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(71) Applicant

(51) INT CL⁴
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C3H 640 645 656 674 B7P
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DNA Cloning: A Practical Approach. Vol II 1985, pages 191-211.
Nature 1982 Vol 296 pages 171-173

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Nature 1982 Vol 298 pages 171-173
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C3H
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(54) Vaccines against melanoma

(57) Peptides or proteins related to a
melanoma associated antigen, P97, may
be produced in large quantities via
recombinant DNA techniques and/or by
chemical synthetic methods. The
peptides or proteins can be expressed
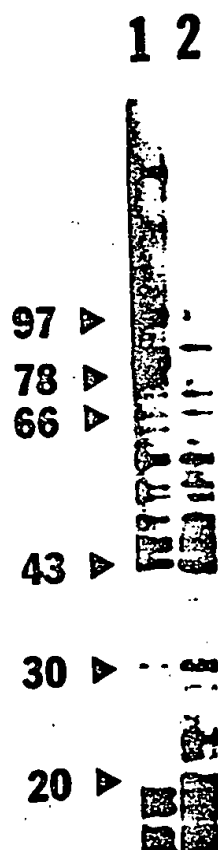by an inactivated or live recombinant
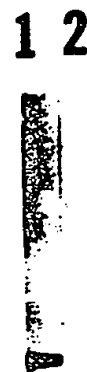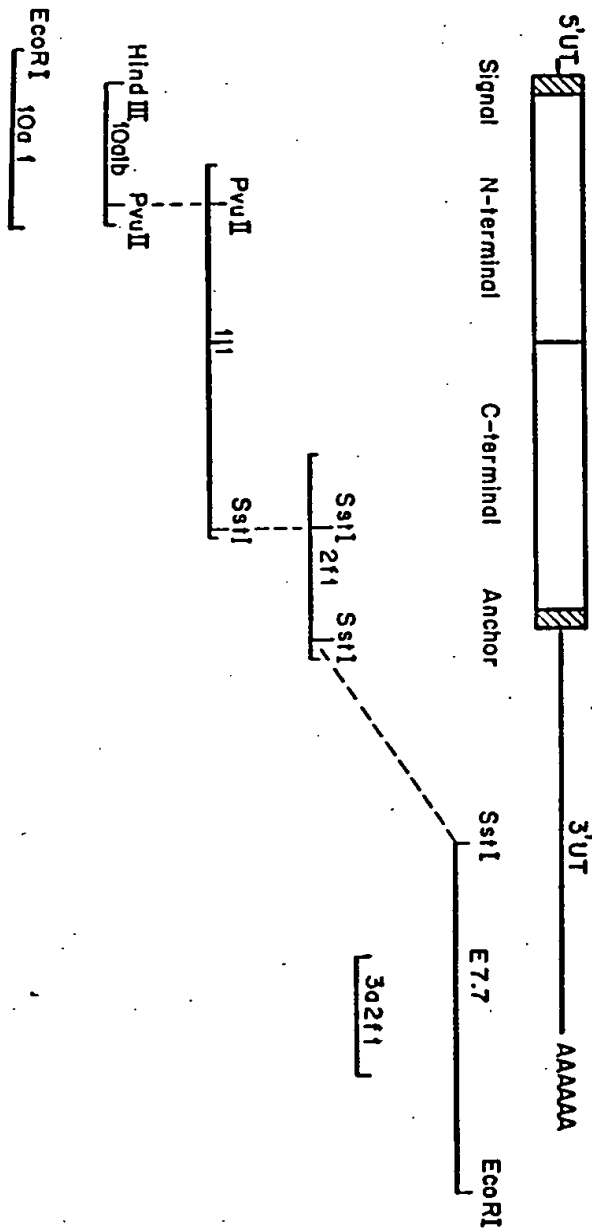virus, e.g. a vaccinia virus.

FIG. 1A   FIG. 1B

FIG. 2

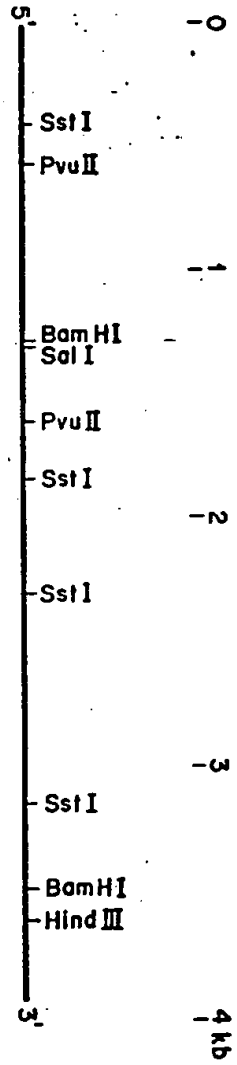p97 cDNA Construct

FIG. 2A
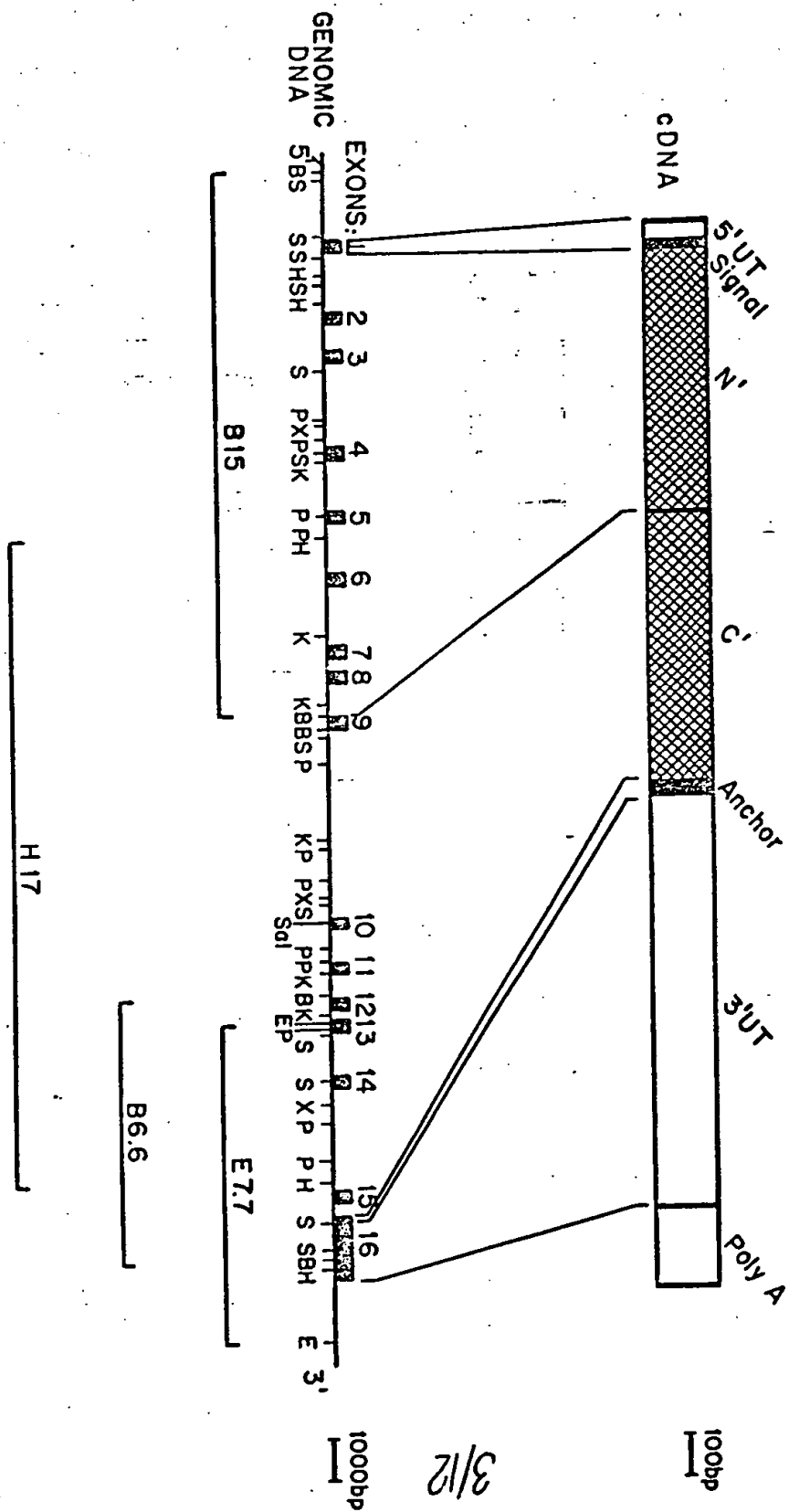
```
                                                                          90
CCG GAC TTC CTC GGA CCC GGA CCC AGC CCC                                   30

ATG CGC GGT CCG AGC GGG GCT CTG TGG CTG  CTC CTG GCT CTG CGC GGC ...  ATG GAG GTG CGG TGG TGC GCC ACC TCG GAC
MET Arg Gly Pro Ser Gly Ala Leu Trp Leu  Leu Leu Ala Leu ...          Met Glu Val Arg Trp Cys Ala Thr Ser Asp   90
                                                                                                                 30

CCA GAG CAG CAC AAG TGC GGC AAC ATG AGC  GAG GCC TTC GAA GAG ACC ...  TCC CTC TGC GTC CGG GGC AAG GAG CAC GGC  180
Pro Glu Gln His Lys Cys Gly Asn Met Ser  Glu Ala Phe Glu ...          Ser Leu Cys Val Arg Gly Lys Glu His Gly   60

GAC CAC TGC GTG CAG CTC ATC GCC GCC CAG  GAG GCT GAC ATC ACT ...      GTC GTC AGG AGC TCC CAT GTG ACC           270
Asp His Cys Val Gln Leu Ile Ala Ala Gln  Glu Ala Asp Ile Thr ...      Val Val Arg Ser Ser His Val Thr           90

CTG AAG CCG GTG GTG GGC GAA GTG TAC GAT  CAA GAG GTC GGT TAC CAT ...  CTG GTG GAG AGC                           360
Leu Lys Pro Val Val Gly Glu Val Tyr Asp  Gln Glu Val Gly Tyr ...      Leu Val Glu Ser                          120

ATT CAC ACC CTG AAA GGC GTG AAG TCC TGC  CAC ACG GGC ATC AAT CGC ...  GTG CCC GTG GGG ACC AGT                   450
Ile His Thr Leu Lys Gly Val Lys Ser Cys  His Thr Gly Ile Asn Arg ...  Val Pro Val Gly Thr Ser                   150

GGC CGC TCG ATG GGC TGC GAT GTA          CTC AAA GCT GAC TAT TTT ...  AGC TGC GTC CCG GCA GGA GAG ACC AGT       540
Gly Arg Ser Met Gly Cys Asp Val          Leu Lys Ala Asp Tyr Phe ...  Ser Cys Val Pro Ala Gly Glu Thr Ser       180

TAC TCT GAG TCC CTC CGC CTC TGC AGG      GGT GAC AGC TCT GAA GGG ...  AAG AGC CCC CTG GAG AGA TAC TAC GAC TAC   630
Tyr Ser Glu Ser Leu Arg Leu Cys Arg      Gly Asp Ser Ser Glu Gly ...  Lys Ser Pro Leu Glu Arg Tyr Tyr Asp Tyr   210

AGC GGG GCC TTC CGG TGC CTG GCG GAA GGG  GCA GGG GAC GTG GCT TTG ...  ACG GTA CTG GAG AAC ACC AAG AGG ACG       720
Ser Gly Ala Phe Arg Cys Leu Ala Glu Gly  Ala Gly Asp Val Ala Phe ...  Thr Val Leu Glu Asn Thr Lys Arg Thr       240

CTT CCC TCC TGG GGC CAG GCC CTG CTC TCA  CAG GAC TTC GAC CTG ...      AGC CGG GCC GAT GTC ACC CTG TCG CAG GAG   810
Leu Pro Ser Trp Gly Gln Ala Leu Leu Ser  Gln Asp Phe Asp Leu ...      Ser Arg Ala Asp Val Thr Leu Trp Arg Gln   270

TGC CAT CTG GCT CCT GCC CAC GCC          CTG GTG GTC CGG GCC ...      CTC ATC TTC CGG CTG CTC AAC GAA CTC TCG   900
Cys His Leu Ala Pro Ala His Ala          Leu Val Val Arg Ala ...      Leu Ile Phe Arg Leu Leu Asn Glu Leu Ser   300

CGT TTC AGC CAC GAG GGC AGC AGC TTC      CAG ATG TTC AGC TCT ...      AAG GAT CTA CTC TTC AAA GAC TCT ACC TCG   990
Arg Phe Ser His Glu Gly Ser Ser Phe      Gln Met Phe Ser Ser ...      Lys Asp Leu Leu Phe Lys Asp Ser Thr Ser   330

GAG CTT GTG CCC ATC GCC ACA CAG ACC TAT  GAG TGG TAC CAT GAG CTG ...  GCC ATG AAG GGT CTG CTG CTG TGT CAC CCC AAC  1080
Glu Leu Val Pro Ile Ala Thr Gln Thr Tyr  Glu Trp Tyr His Glu Leu ...  Ala Met Lys Gly Leu Leu Leu Cys His Pro Asn  360

CGC CTG CCC TAC CTG CGG TGG TGT GTC      CTC ACT CCC ATC CAG ...      GAC ATG GCG GCC GTC GCC TTC CGC CGG CAG CGC   1170
Arg Leu Pro Tyr Leu Arg Trp Cys Val      Leu Ser Thr Pro Ile Gln ...  Asp Met Ala Ala Val Ala Phe Arg Arg Gln Arg   390

CTC AAG CCA ATC GAG CAA CAC TGC TCA GCC  AAG TCC ATC GGC ATG ...      CAG GAG GTC GAC GCT GAG GTC ACC CTA         1260
Leu Lys Pro Ile Glu Gln His Cys Ser Ala  Lys Ser Ile Gly Met ...      Gln Glu Val Asp Ala Glu Val Thr Leu         420

AGT GGC GAC ATT TAC ACG GCG GGG AAG      CAC TAT GCC CTG GTT ...      CAC TAC GCC GAA AGC AGC AAC TCG           1350
Ser Gly Asp Ile Tyr Thr Ala Gly Lys      His Tyr Ala Leu Val ...      His Tyr Ala Pro Glu Ser Ser Asn Ser       450
```

FIG. 3A

```
TAC TAC GTG GTG GCC GTG AGA CGG GAC   AGC TCC CAC GCC TTC ACC TTC GAT GAG CTT   CGG GCC AAG CGC TCC TGC CAC GCC GGT TTC      1440
Tyr Tyr Val Val Ala Val Val Arg Arg Asp  Ser Ser His Ala Phe Thr Leu Asp Glu Leu  Arg Gly Lys Arg Ser Cys His Ala Gly Phe       480

GGC AGC CCT GCA GGC TGG GAT GTC CTC GTG   GCT CCC CTT ATT CAG AGA GGC TTC ATC CGG   CCC AAG GAC TGT GAC GTC CTC ACA GCA GTG      1530
Gly Ser Pro Ala Gly Trp Asp Val Pro Val  Gly Ala Leu Ile Gln Arg Gly Phe Ile Arg  Pro Lys Asp Cys Asp Val Leu Thr Ala Val       510

AGC GAG TTC AAT GCC ACC TGC TGC CCC   ACC AAG AAC CCC AAG AAC TAC TCC TCG   CTG TGT GCA CTG TGC GCG GAG GAC CAG      1620
Ser Glu Phe Asn Ala Ser Cys Cys Pro  Val Asn Asn Pro Lys Asn Tyr Ser Ser  Leu Cys Ala Leu Cys Ala Glu Asp Gln       540

CGG CGC AAC AAG TGT GGC GCC AAC AGC CAG   TAT TAC CGC CGT CGT GTC CTG GTG GGT GAC GTT   AGG TGC CTG GTG GTC AAT GCC GCA GAT GCT GGT GAC GTT      1710
Gly Arg Asn Lys Cys Gly Ala Asn Ser Gln  Tyr Tyr Arg Arg Arg Gly Ala Asn Ala Gly Asp  Arg Cys Leu Val Asn Ala Ala Gly Asp Val       570

GCC TTC GTC ACG CAC ACA TTT CAC   AAC ACA TCC AGG CTC AGG TCA GAG   AGG TCA CTC AGG GAC TAT GAA      1800
Ala Phe Val Thr His Thr Phe His  Asn Thr Asn Gly Asp His Ser Glu  Arg Ser Glu Asp Tyr Glu       600

CTG CTG TGC CCC AAC GGG CCG CGA GCC GAG   GTG TCC CAG TTT GCA GCC CTG AAC CTG GCA   CAG ATA CCA CCC CAC GTG ATG CGG      1890
Leu Leu Cys Pro Asn Gly Ala Arg Ala Glu  Val Ser Gln Phe Ala Ala Leu Asn Leu Ala  Gln Ile Pro Pro His Val Met Arg       630

CCC GAC ACC ATC TTC ACC GTG TAT GGA   CTG GAC GAC AAG GCC CAG CTG TTT GGA   GAC GAC AAT AAC AAG GGG TTC AAA ATG      1980
Pro Asp Thr Ile Phe Thr Val Tyr Gly  Leu Asp Asp Lys Ala Gln Leu Phe Gly  Asp Asp His Asn Lys Asn Gly Phe Lys Met       660

TTC GAC TCC AAC TAT CAT GGC CAA GAC   CTG CTT TTC TTC AAG GAT GCC GTC ACC   GTG CCT GTC GGA GGA GGG CTG TAC CGC      2070
Phe Asp Ser Asn Tyr His Gly Gln Asp  Leu Leu Phe Phe Lys Asp Ala Val Thr  Val Pro Val Gly Gly Glu Leu Thr Tyr Arg       690

GGG TGG CTG GGC GGC TAC CTG GAC GCG   CTG GAA GGG ATG GGC GGG GCG GCG   GGC GCA GCG GCC CCG CCC GGG GCG CCC      2160
Gly Trp Leu Gly Gly Tyr Leu Asp Ala  Leu Glu Gly Met Gly Gly Ala Arg Ala  Gly Ala Ala Ala Pro Pro Gly Ala Pro       720

CTC CTC CCG CTG CTG CTC CTC GCC   GCC CGC CCG CTC CTC CCG CCG CTG TCC TCC   CGG CCG CCC CCC AGA GCT CCG ATG CCC      2250
Leu Leu Pro Leu Leu Leu Leu Ala  Ala Arg Leu Pro Pro Pro Ala Leu Cys Ser  Arg Pro Pro Pro Arg Ala Pro Met Pro       738

GCC CGG CGG GTT TCC GGG TCT CGC   GCT GCG GAA TCC AGA AGG CTC GCG A..       2308
Ala Arg Arg Val Ser Gly Ser Arg  Ala Ala Glu Ser Arg Arg Leu Ala

:::  ::: :::  :::  :::    :::  :::  ::: :::
:::  ::: :::  :::  :::    :::  :::  ::: :::
:::  ::: :::  :::  :::(1280 bp)....:::  :::  ::: :::
:::  ::: :::  :::  :::    :::  :::  ::: :::

GAC GAT TCC TTG GTT TTT GTG CGG TGA GAA CTG TGT TTC TGT CTC   GCT AAC TCT CTA CCG TGC CGT GGC CAT      3678

TGA AGG TGT GCC CTG CGG TGC AGT GTA   AGT GAC GCT GGA TTC TCA GGT GAC AGC AGG   GGG CCC CTG CTG CAG AGC AGG      3768

ATG TTG GTT CGT TTC TAA AAT AAA GCC AAA   CAA GCC ACA TGC CGA GGC TTG GAC CCT   GAT AAA AAA      3840
```

FIG. 3B

FIG. 4

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FIG. 5

FIG. 6.

FIG. 7A   FIG. 7B

FIG. 8

2138637

FIG. 9

Serum Antibody Titers in Mice
Immunized with p97 Vaccines

Legend:
☒ Max. Titer
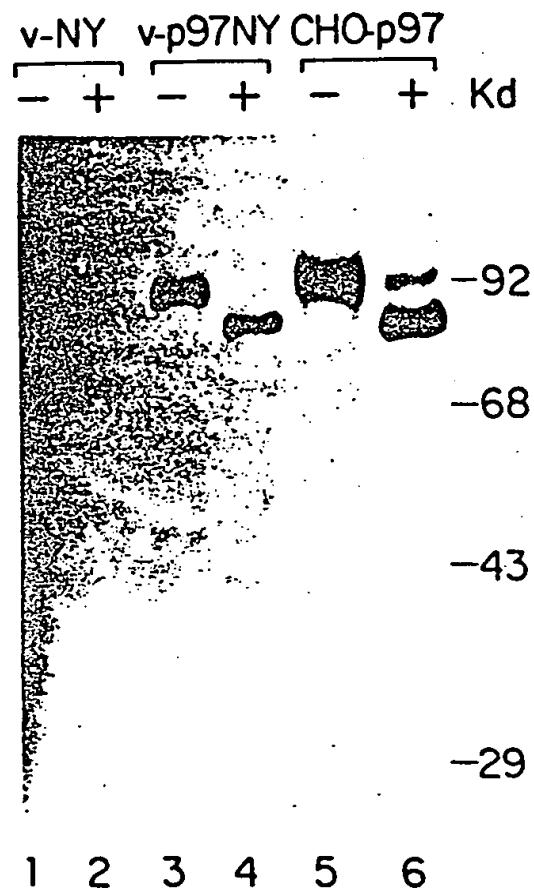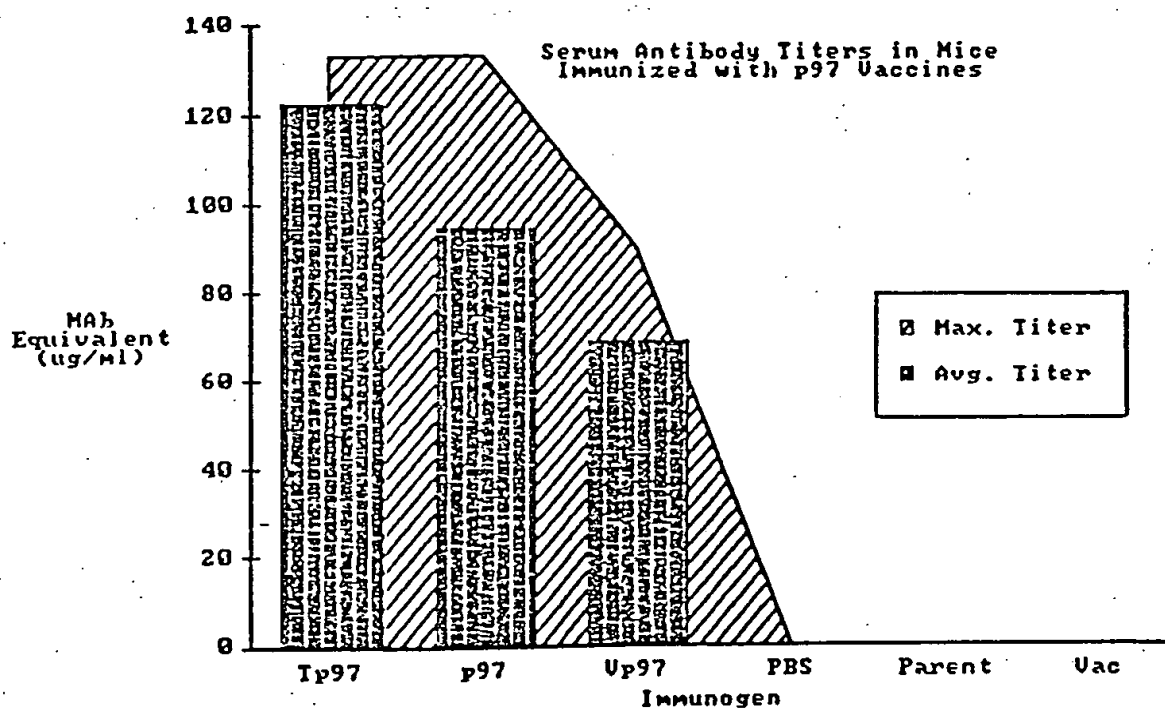■ Avg. Titer
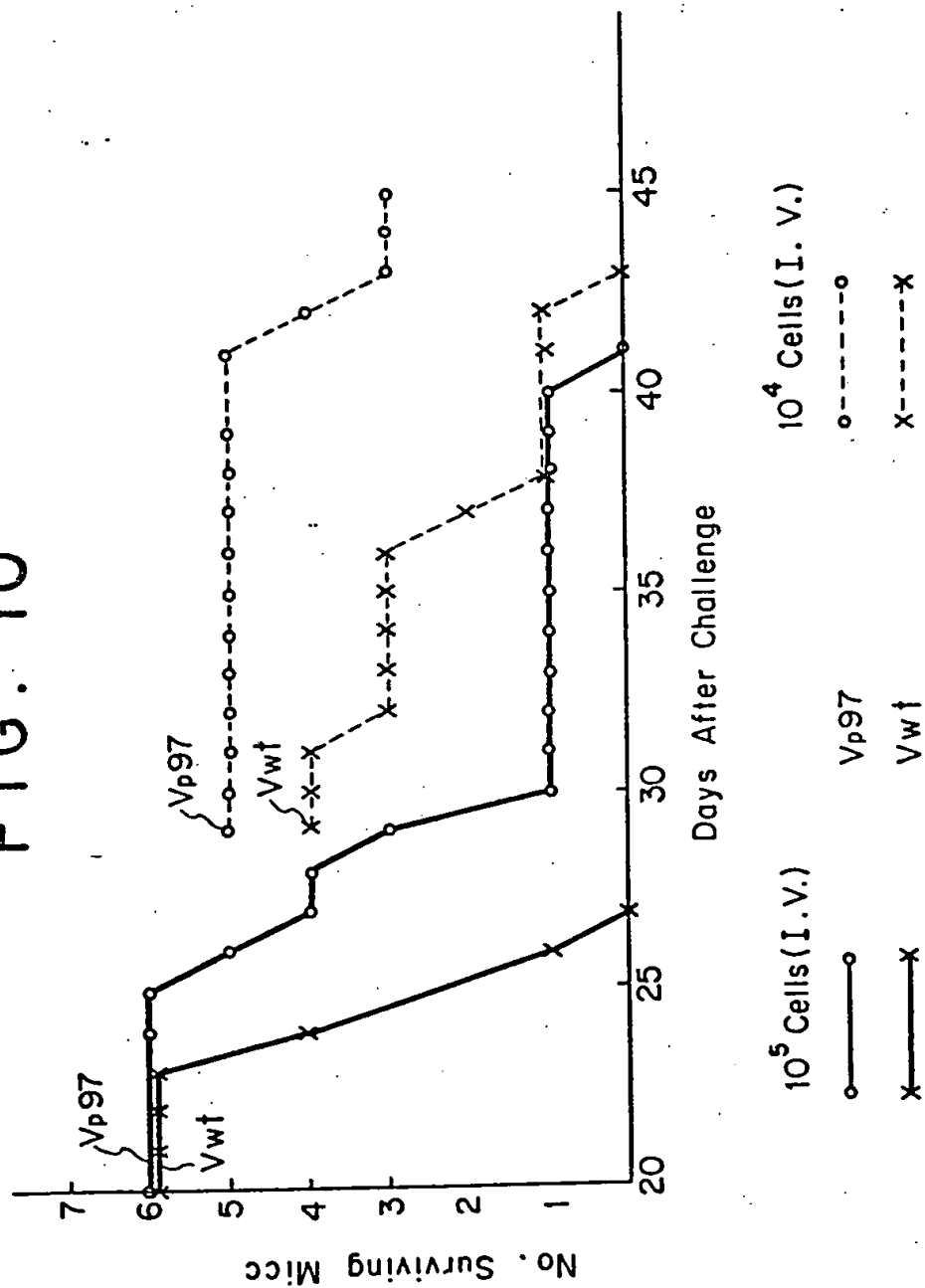
FIG. 10

a cell surface component of melanoma cells.

2. Background of the invention
2.1. Tumor-associated antigens

5   Work with experimental animals, particularly rodents, has shown that most tumors induced by oncogenic
viruses express antigens encoded by the viral genome, and that immunization with these antigens can lead
to rejection of a subsequent challenge of tumor cells induced by the same virus. Although much of this work
was done with laboratory strains of virus, such as SV40, polyoma virus, and Friend, Moloney, or Rauscher
murine leukemia viruses, horizontal and vertical transmission of oncogenic viruses in nature have been
10   demonstrated; indeed a commercial vaccine against virus-induced feline leukemia and sarcoma is now
available.

By contrast, a viral etiology of most human cancer has not been demonstrated. Notable exceptions are
hepatitis virus (hepatoma), herpes simplex virus (cervical carcinoma), and Epstein Barr virus
(nasopharyngeal carcinoma). However, during the past two decades it has been established that some
15   human tumor cells express tumor antigens, i.e., antigens that distinguish the tumor cells from their normal
cellular counterparts; some patients mount cell-mediated or humoral immune responses against these
antigens (Hellstrom et al. 1968, Nature, 220:1352; Morton et al., 1968, Science 162: 1279-1281; Shiku et al.,
1976, J. Exp. Med. 144: 873-881). Some of the targets of these immune responses are oncofetal or
differentation antigens encoded by the human genome (Hellstrom et al., 1970, Int. J. Cancer 6: 346-351).
20   Until recently the molecular nature of the tumor antigens was unknown, and the degree of tumor
specificity of the immunological reactions was unclear. Attempts to utilize this information in developing
cancer diagnostic assays or cancer therapies have been largely unsuccessful. Since spontaneous tumor
regressions are extremely rare, one may also conclude that the immune responses demonstrated in vitro
were ineffective in vivo; for example, while antibodies and lymphocytes obtained from a cancer patient may
25   be effective in killing tumor cells in vitro, the immune response of the same cancer patient has no effect in
vivo.

The introduction by Kohler and Milstein of the monoclonal antibody technique (1975, Nature 256: 495-497)
led to intensified searches for human tumor antigens, since it provided the means to define such antigens,
both at the molecular level and with respect to specificity (Hellstrom and Brown, 1979, In "The Antigens", M.
30   Sela, ed., Academic Press, Vol. V: 1-66). Over the past several years a large number of tumor-associated
antigens have been described, most of which have been defined by mouse monoclonal antibodies: Reisfeld
and Sell, eds., Monoclonal Antibodies and Cancer Therapy, UCLA Symposia on Molecular and Cellular
Biology, New Series, Vol. 27, Alan R. Liss, Inc. New York, 1985, pp. 1-609. Although virtually all of the antigens
which have been well characterized have proven to be oncofetal or differentiation antigens, and their
35   specificity for tumors has been found to be quantitative rather than qualitative, several antigens are
sufficiently specific for neoplastic versus normal cells (generally corresponding to a factor of 10 to 1,000
times) to be used as potential targets for identifying tumor cells and for therapy. Human monoclonal
antibodies to tumor antigens have also been obtained (Cote et al., 1983, Proc. Natl. Acad. Sci. 80: 2026-2030).
This supports the previously cited evidence that some cancer patients mount an immune reaction to their
40   tumors.

More than half of the tumor-associated cell surface antigens so far identified are proteins or glycoproteins
encoded by the human genome (rather than by endogenous or exogenous viruses), with the remainder
being glycolipids, resulting from abnormal expression or regulation of glyosyl transferases.

2.2. Melanoma associated p97 antigen

45   The p97 antigen is a tumor-associated antigen that was first identified in human melanoma by using
monoclonal antibodies (Brown et al., 1980, J. Biol Chem. 255:4980-4983; Dippold et al., 1980, Proc. Natl.
Acad. Sci. USA 77:6114-6118; Woodbury et al., 1980, Proc. Natl. Acad. Sci. USA 77:2183-2187). The p97
antigen has been studied extensively with regard to its expression in normal and neoplastic tissues, and is
present in most human melanomas and in certain fetal tissues, but is found in only trace amounts in normal
50   adult tissues (Brown et al., 1981, J. Immunol. 127:539-546; Brown et al., 1981, Proc. Natl. Acad. Sci. USA
78:539-543; Garrigues et al., 1982, Int. J. Cancer 29:511-515). p97 has been used as a target for diagnostic
imaging of melanomas in human clinical trials (Larson et al., 1983, J. Clin. Invest. 72:2101-2114).

p97 is a monomeric cell surface sialoglycoprotein, with an apparent molecular weight (MW) as measured
55   by sodium dodecylsulfate-polyacrylamide gel electrophoresis (SDS-PAGE) of slightly less than 97,000
daltons. Monoclonal antibodies have defined three major antigenic sites which are present on a stable 40,000
dalton tryptic fragment (Brown et al., 1981, J. Immunol. 127:539-546); however, the complete sequence of
p97 has not been reported. At least two other independently characterized human melanoma-associated
antigens, gp95 (Dippold et al., 1980, Proc. Natl. Acad. Sci. USA 77:6114-6118) and gp87 (Knosravi et al., 1985,
60   Int. J. Cancer 35:73-80) appear to be identical to p97 as analyzed by sequential immunoprecipitation.

The N-terminal amino acid sequence of p97 is homologous to transferrin, and like transferrin p97 binds
iron (Brown et al., 1982, Nature, London, 296:171-173). Analysis of somatic cell hybrids and in situ
hybridization has shown that the p97 gene, like the genes for transferrin and transferrin receptor, is located
on chromosomal region 3q21-3q29 (Plowman et al., 1983, Nature, London, 303:70-72; Yang et al., 1984, Proc.
65   Natl. Acad. Sci. USA 81:2752-2756). These observations suggest that p97 plays a role in iron metabolism.

SPECIFICATION

Vaccines against melanoma

The present application is a continuation in part of copending application Serial Number 827,313 filed February 7, 1986, which is hereby incorporated by reference in its entirety.

1. *Field of the invention*

The present invention is directed to vaccine formulations which can induce an immune response that selectively destroys melanoma cells in a vaccinated individual. Accordingly, a peptide or protein related to a melanoma associated antigen is produced in large quantities via recombinant DNA techniques and/or by chemical synthetic methods. The peptide or protein of the present invention can be used as an immunogen in a vaccine formulation. In certain embodiments where the peptide or protein related to a melanoma associated antigen is expressed by a recombinant virus, the recombinant virus itself may be used as an immunogen in a vaccine formulation. The invention also provides for processes which include the use of recombinant DNA techniques as well as chemical synthetic methods that enable the production of peptides or proteins related to the melanoma associated antigen in large quantities.

The invention is illustrated by way of example using as immunogens peptides related to p97, a monomeric cell surface sialoglycoprotein with an apparent molecular weight of slightly less than 97,000 daltons which is

associated antigen such as the melanoma associated p97 antigen. According to the invention, a number of
vaccine formulations are possible. For example, the immunogen of a "subunit vaccine" of the present
invention comprises a peptide or protein related to p97 which may be formulated with an appropriate
adjuvant. Such peptides or proteins comprise amino acid sequences derived from all or a portion of the
5   amino acid sequence of p97 substantially as depicted in Figure 3 including but not limited to altered amino   5
acid sequences in which functionally equivalent amino acid residues are substituted for residues within the
sequence resulting in a silent change, and/or modified or processed amino acid sequences, as for example,
glycosylated amino acid sequences, as for example, glycosylated amino acid sequencies, phosphorylated
amino acid sequences, etc. or chemically modified amino acid sequences. Hereinafter, the peptides or
10 proteins of the present invention which are related to the melanoma associated p97 antigen whether altered,   10
unaltered, modified or unmodified, will be referred to as "p97 related peptides". Where the p97 related
peptide is a hapten (i.e., antigenic but not immunogenic) the hapten can be conjugated to a carrier molecule
that confers immunogenicity.
    The p97 related peptides of the invention may be produced using recombinant DNA techniques and/or
15 chemical synthetic methods. When p97 related peptides are chemically synthesized such synthetic p97   15
related peptides can comprise those amino acid sequences derived from regions of p97 that are expected to
be antigenic (Hopp and Woods, 1981, Proc. Natl. Acad. Sci. USA, 78:3824-3828). Where the p97-related
peptides of the present invention are produced by using recombinant DNA techniques, a nucleotide
sequence which encodes the whole or a portion of p97 is inserted into a recombinant expression vector such
20 as a virus or a plasmid which, in an appropriate host, can direct the expression of a p97 related peptide that   20
can be purified from the culture medium. The nucleotide sequence inserted is derived from all or portions of
the p97 sequence substantially as depicted in Figure 3 including but not limited to nucleotide sequences in
which functionally equivalent nucleotide codons are substituted for codons within the sequence resulting in
a silent change; in other words, different codons which encode the same amino acid or its functional
25 equivalent may be substituted within the sequence depicted in Figure 3. When a plasmid expression vector is   25
used, one that is suitable for expression in eukaryotic cells is preferred, but a prokaryotic expression vector
may also be used.
    In another embodiment of the invention where the expression vector is a recombinant virus, a vaccine may
be formulated as a viral vaccine, in which case the immunogen comprises the recombinant virus that
30 expresses a p97 related peptide. Depending upon the nature of the recombinant virus used as the   30
immunogen, either an inactivated virus vaccine or a live virus vaccine may be formulated. Appropriate
immunization with the vaccine formulations of the present invention can result in the induction of an
immune response which leads to the destruction of melanoma cells in the immunized subject.
    The invention also describes a system in which the vaccine formulation can be tested and outlines how the
35 test should be performed. For example, the vaccine formulations can be evaluated for efficacy in animal   35
models, initially rodents, then in non-human primates, and finally in humans, preferably in patients who are
in remission but have a high probability of recurrence due to micrometastases.

    4. Brief description of the Figures
40   Figure 1 represents an autoradiograph of the cell-free translation products of p97 mRNA resolved by   40
SDS-PAGE. In Figure 1A, lane 1 represents the translation products of p97 enriched mRNA, whereas lane 2
represents the translation products of unenriched mRNA, each derived from 0.5μℓ total translation products
of 5ng mRNA. In Figure 1B, lane 1 represents the translation products of p97 enriched mRNA whereas lane 2
represents the translation products of unenriched mRNA, each derived from 5μℓ translation products of 5ng
45 mRNA immunoprecipitated with anti-p97 serum.   45
    Figure 2 is a diagrammatic representation of the structure of p97 mRNA. The arrangement of the coding
region (from the signal sequence to the anchor sequence) and the non-coding region (3'UT) as well as the
duplicated domain structure of the p97 precursor (open bar) is indicated. The location of various restriction
enzyme recognition sequences are indicated above the mRNA. The relative positions of four cDNA clones are
50 indicated below the mRNA structure. The cDNA clone p97-3a2fl (3a2fl) was isolated from a cDNA library in   50
which the cDNAs were transcribed on oligo(T)-primed p97-enriched mRNAs and cloned in pBR322; whereas,
cDNA clones p97-2fl (2fl), p97-1jl (1jl), and p97-10al (10al) were isolated by priming cDNA synthesis with
oligonucleotides that encode p97 exon sequences and cloning the resulting cDNA fragments into
lambda-gt10. Figure 2A is a diagrammatic representation of genomic clones B15, H17, B6.6 and E7.7 which
55 were cloned in lambda L47.1.   55
    Figure 3 represents the nucleotide sequence of human p97 precursor cDNA and its deduced amino acid
sequence. The N-terminal amino acid residues determined previously by protein sequencing were identical
to those predicted from the nucleotide sequence (amino acid residue numbers 21-30). The potential
glycosylation sites at amino acid residues 38, 135 and 515 (open bar) and the membrane anchor region at the
60 C-terminus (solid bar) are indicated. One polyadenylation signal (AATAAA indicated in a box) was detected at 60
position 3847, which is 50 base pairs upstream of a polyadenylated tract.
    Figure 4 represents a comparison of the predicted amino acid sequences of the p97 precursor and that of
human serotransferrin (Yang et al., 1984, Proc. Natl. Acad. Sci. U.S.A. 81:2752-2756; Davis et al., 1985, J. Mol.
Biol. 181:111-121). Conserved residues have been boxed. Tyrosine, histidine and arginine residues
65 implicated in iron binding of transferrin (Metz-Boutigue et al., 1984, Eur. J. Biochem. 145:659-676) are   65

2.3. Cancer vaccines

Studies in experimental animals, usually mice, have shown that immunization with living or killed cancer cells can lead to rejection of a subsequent challenge of viable cancer cells. Attempts to immunize with cell-free material have generally been less successful, but some successes have been reported. (For a review
5 see Hellstrom and Brown, 1979, in *The Antigens*, M. Sela ed. Academic Press, Vol. V: 1-66). In many cases the target antigens responsible for the protective effects have been virally encoded, but in many other cases the nature of the antigen which elicits a protective immune response is unknown.

Studies in humans are much more difficult, and the effectiveness of cancer vaccines is disputed, in spite of some reports of success. In many cases the vaccine preparations have consisted of irradiated tumor cells or
10 tumor cells killed by exposure to certain chemical agents. Because pure human tumor-associated antigens have not been available there are no reports of their use in vaccines.

A major theoretical objection to the proposed use of cancer vaccines in humans is that humans who are "vaccinated", for example, with killed cancer cells or cell-free preparations, will be immunologically unresponsive because the tumor antigens that may be the targets of the immune response are present, albeit
15 in trace amounts only, in some normal cells and will thus be perceived by the immune system as "self". Most, if not all, tumor-associated antigens detected in human tumors by monoclonal antibodies are also present in some normal tissues, and there is little evidence that cancer patients respond to them effectively *in vivo*. There is evidence that suppressor cells play a major role in down-regulating the immune response to tumor antigens (Nepom et al., 1983, Experientia, 39:235-242). Furthermore, a suppressor cell response induced by
20 one set of tumor antigens may prevent the induction of an effective tumor-destructive response to another set of tumor antigens, which by themselves would not induce suppression (Hellstrom et al., 1983, in Biomembranes, A. Nowotny ed., Plenum Press, pp.365-388).

2.4. Recombinant DNA techniques and vaccinia virus

25 The use of recombinant DNA technology for the production of subunit vaccines to protect against infections involves the molecular cloning and expression in an appropriate vector of genetic information coding for proteins which can elicit an immune response against the protein in the host animal. Recently, a novel approach has been described which is potentially useful in the production of subunit vaccines (Mackett et al., 1982, Proc. Natl. Acad. Sci. 79: 7415-7419; Mackett et al., 1984, J. Virol. 49: 857-864; Panicali, D. and
30 Paoletti, E., 1982, Proc. Natl. Acad. Sci. 79: 4927-4931). This approach involves the use of vaccinia virus as a vector to express foreign genes inserted into its genome. Upon introduction into host animals, the recombinant vaccinia virus expresses the inserted foreign gene and thereby elicits a host immune response to such gene products. Since live recombinant vaccinia virus can be used as a vaccine, this approach combines the advantages of both subunit and live vaccines.
35 Vaccinia virus contains a linear double-stranded DNA genome of approximately 187 kilobase pairs and replicates within the cytoplasm of infected cells. These viruses contain a complete transcriptional enzyme system (including capping, methylating and polyadenylating enzymes) within the virus core that are necessary for virus infectivity. Vaccinia virus transcriptional regulator sequences (promoters) allow for initation of transcription by vaccinia RNA polymerase but not by host cell RNA polymerase.
40 Expression of foreign DNA in recombinant vaccinia viruses requires the ligation of vaccinia promoters to protein-coding DNA sequences of the foreign gene. Plasmid vectors, also called insertion vectors, have been constructed to insert chimeric genes into vaccinia virus. One type of insertion vector is composed of: (a) a vaccinia virus promoter including the transcriptional initiation site; (b) several unique restriction endonuclease cloning sites located downstream from the transcriptional start site for insertion of foreign
45 DNA fragments; (c) nonessential vaccinia virus DNA (such as the TK gene) flanking the promoter and cloning sites which direct insertion of the chimeric gene into the homologous nonessential region of the virus genome; and (d) a bacterial origin of replication and antibiotic resistance marker for replication and selection in *E. coli*. Examples of such vectors are described by MacKett (Mackett et al., 1984, J. Virol. 49: 857-864).

Recombinant vaccinia viruses are produced by transfection of recombinant bacterial insertion plasmids
50 containing the foreign gene into cells previously infected with vaccinia virus. Homologous recombination takes place with the infected cells and results in the insertion of foreign gene into the viral genome. The infected cells can be screened using immunological techniques, DNA plaque hybridization, or genetic selection for recombinant viruses which subsequently can be isolated. These vaccinia recombinants retain their essential functions and infectivity and can be constructed to accommodate approximately 35 kilobases
55 of foreign DNA.

Foreign gene expression can be detected by enzymatic or immunological assays (for example, immunoprecipitation, radioimmunoassay, or immunoblotting). Naturally occurring membrane glycoproteins produced from recombinant vaccinia infected cells are glycosylated and may be transported to the cell surface. High expression levels can be obtained by using strong promoters or by cloning multiple
60 copies of a single gene.

3. Summary of the invention

Vaccine formulations are described which may be used to induce an immune response that selectively destroys melanoma cells in vaccinated individuals. More specifically, the vaccine formulations of the present invention comprise an immunogen that induces an immune response directed against a melanoma

nucleotide sequence encoding all or part of p97 can be used to produce large amounts of pure p97 related peptides *in vitro* in which case the gene products can be purified from the cells in culture and used as immunogens in submit vaccine formulations. Purification of the p97 related peptide may be accomplished using a variety of biochemical methods, including immunoaffinity purification using monoclonal antibodies.

5   In addition, purification of the p97 related peptide can be facilitated by modifying the DNA sequences that encode the p97 related peptides so that the sequences responsible for anchoring the protein in the plasma membrane are removed yet the sequences responsible for transporting the protein to the cell membrane are not removed, so that a truncated antigenic molecule is secreted into the culture medium by the host cell. In the case of p97 related peptides produced by prokaryotic cells, lack of appropriate postranslational

10 modifications may result in an antigenically inactive product, which may have to be activated by appropriate chemical or other treatments.

In certain embodiments, where the expression vector is a virus, the virus itself can be formulated as a vaccine. In such cases inactivated recombinant virus vaccines can be prepared. Where the expression vector is an infectious recombinant viruses that does not cause disease in the host either an inactivated viral vaccine

15 or a live virus vaccine preparation which provides for substantial immunity can be formulated. A particularly useful expression vector for this purpose is a recombinant vaccinia virus which expresses the p97 related peptides of the present invention. To this end a nucleotide sequence coding for all or part of the p97 antigen can be inserted into a vaccinia virus vector that is capable of directing the expression of the sequence in a appropriate host. The invention includes the use of other virus expression vectors as vaccines, more

20 particularly, adenoviruses.

In another embodiment of the present invention, the deduced amino sequence of p97 may be be examined for sequences with properties, particularly hydrophilicity, that are predictive of the presence of that sequence at the surface of the protein molecule and of its probable antigenicity and/or immunogenicity. These p97 related peptides may be chemically synthesized and used as immunogens in vaccine formulations.

25 The invention also provides a method for producing p97 related peptides that may be used for purposes other than vaccine production. The p97 related peptide may be used to immunize animals so as to produce antisera or monoclonal antibodies specific for the melanoma cells of interest. These may be used as a component in a diagnostic assay, or for the affinity purification of radiolabeled drug-linked, or toxin-linked antibodies to be used for cancer therapy.

30 The invention is demonstrated by way of the examples in which we describe the construction of a p97-based vaccine against human melanoma. However, the methods and compositions described herein are not limited to the construction of vaccines using p97, but can be applied to other tumor-associated antigens.

The invention is presented as follows, solely for the purpose of clarity of description: (a) the nucleotide and amino acid sequence of p97; (b) p97 related peptides prepared by chemical synthetic methods; (c) p97 rela-

35 ted peptides produced by expression vector-host systems; (d) immunological characterization of the p97 related peptides; and (e) formulation of vaccines.

5.1.   Sequence analysis of the melanoma associated p97 antigen

The nucleotide sequence of the gene coding for p97 and its derived amino acid sequence are depicted in

40 Figure 3. Functionally equivalent sequences are within the scope of the present invention. These include but are not limited to nucleotide sequences comprising all or portions of the nucleotide sequence depicted in Figure 3 which are altered by the substitution of different codons that encode the same or a functionally equivalent amino acid residue thus producing a silent change as well as amino acid sequences comprising all or portions of the amino acid sequence depicted in Figure 3 which are altered by the substitution of function-

45 ally equivalent amino acid residues within the sequence thus producing a silent change and derivatives thereof which are modified or processed, for example by glycosylation, phosphorylation, etc. or by other chemical modifications.

The subsections below describe the strategy that was used to determine the sequence of p97 as depicted in Figure 3 as well as alternate techniques that could be used to determine the sequence of p97 or other tumor

50 antigens that would be useful in vaccine formulations.

5.1.1.   Identification and characterization of the melanoma associated p97 antigen

The activity and amino acid sequence of the melanoma associated p97 antigen was not known; as a result, identification of the p97 antigen was accomplished using monoclonal antibodies directed against p97. A

55 number of techniques may be used to generate monoclonal antibodies specific for p97. For example, the hybridoma technique developed by Kohler and Milstein (1975, Nature 250:495-497) may be used as follows: mice or rats are immunized with human melanoma cells and lymphocytes collected from the immunized animals are fused with myeloma cells; alternatively, lymphocytes from melanoma patients can be fused with myeloma cells (Cote, et al., 1983, Proc. Natl. Acad. Sci. 80:2026; Haspel et al., 1985, Cancer Res. 45:3951), or

indicated by asterisks (*).

Figure 5 is a diagrammatic representation of a two-dimensional model of the structure of p97 based upon the presence of cysteine residues conserved between the transferrin superfamily members. The three potential glycosylation sites are indicated by asterisks (*). The hydrophobic membrane anchor domain is
5 apparent at the C-terminus of p97 (COOH).

Figure 6 is a diagrammatic representation of the genetic structure of: the p97 cDNA clones and fragment of genomic clone lambda E7.7 used for construction of the p97 expression vector; and the pSV2p97a expression vector. The following abbreviations are used: E, *EcoRI*; P, *PvuII*; Sal, *SaII*; S, *SsTI*; B, *BamHI*.

Figure 7 shows the results of gel electrophoresis in the characterization and immunopurification of
10 recombinant p97 protein. A transfected CHO clone (CHO3+) and SK-MEL 28 human melanoma cells were labeled with ^{35}S-cysteine in the presence (+TM) or absence (−TM) of tunicamycin (TM). Cells were seeded into 100 mm^2 plates and allowed to reach near confluency. Medium was removed and replaced with 3ml cysteine-free medium with or without addition of 1 ug/ml tunicamycin. After 30 minutes at 37°C, 250 uCi per ml L-^{35}S-cysteine (1016 Ci per mmol; New England Nuclear) was added for a further 6 hours. Harvesting of
15 cells, preparation of cell lysates, immunoprecipitation, and SDS-PAGE were as described *supra*. Extracts were immunoprecipitated with p97-specific antibodies, and proteins were analyzed by SDS-polyacrylamide gel electrophoresis (SDS-PAGE). (a), Coomassie blue stained SDS-polyacrylamide gel. Lane 1, protein markers; lane 2, immunopurified p97 shed from transfected mouse B16 cells; lane 3, SK-MEL 28 cells +TM; lane 4, SK-MEL 28 cells −TM; lane 5, CHO3+ cells +TM; lane 6, CHO3+ cells −TM. (b) Autoradiogram of the
20 same gel as in (a).

Figure 8 shows the results of radioimmunoprecipitation of expressed p97 in transfected cells or Vp97a-NY infected cells. BSC cells were infected overnight with wild type vaccinia virus or p97 recombinant vaccinia virus. These viruses or the transfected cell line CHO-p97.A were incubated with ^{35}S-labeled methionine and cysteine with or without tunicamycin at 2ug/ml (Sigma). The cells were lysed six hours later, precipitated
25 with monoclonal antibody 96.5, and separated by electrophoresis on a 10% polyacrylamide gel. The gel was autoradiographed overnight. The tunicamycin treated group is on the right for each group.

Figure 9 depicts the serum antibody titers in mice immunized with p97 vaccines. Tp97 represents five mice immunized with 5×10^6 irradiated M2svp97a.A cells (syngeneic tumor cells transfected and expressing surface p97) in complete Freund's adjuvant, and boosted with the same number of cells in
30 phosphate-buffered saline. p97 is a group of five mice immunized with 100ug purified p97 protein in complete Freund's adjuvant, and boosted with 50ug aqueous protein. Vp97 is a group of five mice immunized and boosted with 10^7 plaque forming units of Vp97a-NY by tail scarification.

Figure 10 depicts the therapeutic effect of vaccination of tumor-challenged mice with a recombinant p97 vaccinia virus (Vp97a-NY). Mice were challenged with 10^5 or 10^4 p97-expressing tumor cells (M2SVp97a.E)
35 intravenously. Two days later, mice were inoculated by tail scarification either with Vp97a-NY or Vwt-NY. Weekly inoculations by tail scarification were repeated, and mouse survival recorded.

5. *Detailed description of the invention*

The present invention is directed to the production of vaccines for the prevention or treatment of
40 melanomas. It is based upon the observation that melanomas have tumor-associated cell surface antigens, such as the p97 antigen, which are present in greater amounts in the melanoma cells than they are in normal tissues. According to the present invention, peptides or proteins related to the melanoma associated p97 antigen (*i.e.*, p97-related peptides) are produced using recombinant DNA techniques and/or chemical synthetic techniques. The p97-related peptides of the present invention comprise amino acid sequence
45 derived from whole or portions of the amino acid sequence of p97 substantially as depicted in Figure 3. These include amino acid sequences derived from Figure 3 which have been altered by the substitution of one or more amino acid residues within the sequence by another amino acid of a similar polarity which acts as a functional equivalent thus resulting in a silent alteration. Substitutes for an amino acid within the sequence may be selected from other members of the class to which the amino acid belongs. For example, the
50 nonpolar (hydrophobic) amino acids include alanine, leucine, isoleucine, valine, proline, phenylalanine, tryptophan, and methionine. The polar neutral amino acids include glycine, serine threonine, cysteine, tyrosine, asparagine, and glutamine. The positively charged (basic) amino acids include arginine, lysine, and histidine. The negatively charged (acidic) amino acids include apartic acid and glutamic acid. Moreover, the p97 related peptides of the present invention, whether or not altered by the substitution of amino acid
55 residues, may be further modified or processed by glycosylation, phosphorylation, etc. or by chemical modifications. These p97 related peptides can be used as immunogens in vaccine formulations that elicit an immune response directed against melanoma cells present in the vaccinated patient.

According to one embodiment of the present invention, recombinant DNA techniques are used to insert nucleotide sequences encoding the p97 antigen into expression vectors that will direct the expression of the
60 p97 related peptides in appropriate host cells. The nucleotide sequences encoding the p97 antigen comprise nucleotide sequences derived from whole or portions of the p97 nucleotide sequence substantially as depicted in Figure 3. Due to the degeneracy of the DNA code for amino acids, (*i.e.*, most amino acids can be encoded by more than one codon) functionally equivalent codons (*i.e.*, different codons which encode the same amino acid or its functional equivalent) may be substituted within the p97 sequence depicted in Figure
65 3 provided the substitution results in a silent change. The expression vector-host cell system which contain a

A more serious problem is that mature proteins differ from nascent chains because of post translational modifications. This problem is particularly acute for cell surface proteins, which are modified more extensively by removal of the signal peptides, addition of carbohydrate side chains, and formation of disulfide bridges. If a polyclonal antiserum is used for polysome immunopurification, the differences in antigenicity
5　between nascent chains and the mature protein may be of little consequence, since during immunization the rabbit or other animal is exposed not only to the native protein but also to partially or completely denatured forms, particularly if Freund's adjuvant has been used. Even if these antibodies represent only a minor fraction of the antibody population there may still be enough present to bind the nascent chains. Unfortunately, preparation of a polyclonal antiserum to a low-abundance proteins may be extremely difficult. Although a
10　monoclonal antibody may be used to purify the antigen for further immunizations, each gram of cultured cells often yields only a microgram of antigen. This is enough to immunize several mice, but barely sufficient for a single rabbit.

Another solution to the problem is to obtain a monoclonal antibody that recognizes antigenic determinants present in nascent chains by using denatured p97 antigen as the immunogen used to prepare the mono-
15　clonal antibody. In the example of the present invention a panel of monoclonal antibodies that recognized three distinct epitopes on the N-terminal 40,000 dalton molecular weight domain of the p97 molecule were available, and we used a pool of monoclonal antibodies each with a different specificity in the hope that one or more of them would bind to nascent chains. The antibodies chosen were highly specific for p97, in that each of them immunoprecipated a single band of p97 from a radiolabeled whole cell lysate, and they had
20　high binding affinities. For the cloning project we chose three IgG2a antibodies, one specific for each other of the three epitopes. In general the chance of success may be increased by using a number of antibodies to distinct epitopes.

When using monoclonal antibodies the question remains of how one can predict whether a given monoclonal antibody or combination of antibodies will recognize the nascent chains and thus be suitable for use in
25　polysome immunopurification. One approach is to determine whether the monoclonal antibody immunoprecipitates antigen that has been translated in the reticulocyte lysate system, relying on the assumption that the in vitro translation product, not being processed, will resemble the nascent chains. An alternative approach is to proceed with the polysome immunoprecipitation on a small scale and then to use in vitro translation to determine whether the mRNA species of interest has been enriched.

30　When the polysome immunopurification technique is used it is important to monitor the purification by measuring mRNA activity. This can be done by translating the mRNA in a reticulocyte lysate system and analyzing the translation products by SDS-PAGE. Although the tumor-associated antigen may be too minor a component of the translation products of unenriched mRNA to be seen among the hundreds of more abundant species, it should be detectable in the translation products derived from the enriched mRNA samples.
35　Alternatively, the Xenopus oocyte translation system can be used, if a sensitive immunoassay is available to detect the translated tumor-associated antigen. For p97 a highly sensitive double determinant immunoassay (DDIA), which employs two monoclonal antibodies specific for two different epitopes of p97, was used for this purpose.

Protein A bound to Sepharose can be used for the polysome immunopurification. The protein A adsorbent
40　has two applications in this procedure. The first is to purify the monoclonal antibodies from the crude ascites fluids, thereby removing contaminating ribonuclease activity. The protein A adsorbent is then used in conjunction with the purified antibodies to immunopurify polysomes bearing the specific nascent chain.

Translation of the mRNA in a reticulocyte lysate system allows the biochemical characterization of the translation product as well as an assessment of its purity.

45

(b)　*Oligonucleotide probes*

Another method that may be used in accordance with the invention to clone the cDNA coding for a tumor-associated antigen such as p97 is to determine a partial or complete amino acid sequence of the antigen and to synthesize an oligonucleotide probe based on the nucleotide sequence deduced from the amino acid sequence. The oligonucleotide may then be used as a primer for cDNA synthesis and as a probe to screen the
50　resulting cDNA library. Accordingly, the melanoma associated p97 protein may conveniently be purified from lysates of melanoma cells by affinity chromatography with a specific monoclonal antibody (Brown, et al., 1982, Nature, London 296:171-173). A nucleotide sequence coding for part of the determined amino acid sequence is then synthesized which can be used as a primer and/or probe. Parts of the amino acid sequence containing amino acid residues coded by a single codon or two codons are most suitable for this purpose.
55　One approach is to synthesize a longer sequence, typically 25 to 60 nucleotides, which represents the most probable coding sequence based upon the known codon usage frequencies in humans. The use of two synthetic oligonucleotides based on different parts of the amino acid sequence facilitates the screening by allowing one to identify spurious positive hybridization signals. Additionally, the use of hybridization conditions that minimize the effect of GC-content on the melting point of DNA hybrids also facilitates the screen-
60　ing. Once a partial cDNA clone has been obtained by this method it may be used as a probe to help obtain a full-length cDNA clone.

(c)　*cDNA expression libraries*
65　Cloning vectors have been developed that allow for expression of the cDNA insert in bacteria. One app-

the technique for producing monoclonal antibodies using Epstein-Barr virus (Cole et al., 1985, The EBV-Hybridoma Technique and its Application to Human Lung Cancer, in Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, Inc., pp. 77-96) can be used to generate monoclonal antibodies directed against p97. In any case, the resulting hybridomas are screened for the production of antibodies that bind to the melanoma
5 cells but do not bind to normal cells.

The monoclonal antibodies directed against p97 described above can be used in a number of ways to facilitate the identification, characterization, cloning and expression of nucleotide sequences which allow for the production of peptides and proteins related to the p97 antigen, in large quantities. For example, the monoclonal antibodies may be used to further characterize the p97 antigen by radiolabeling all the proteins
10 made by the tumor cell, immunoprecipitating the tumor protein with the monoclonal antibody used to iden-tify the p97 antigen, and fractionating the immunoprecipitated proteins by gel electrophoresis. Protein anti-gens are identified as distinct bands on the resulting autoradiograph (Brown et al., 1980, J. Biol. Chem. 255:4980-4983). In addition, the monoclonal antibodies directed against p97 can be used to facilitate cloning as follows: (a) to immunopurify polysomes in order to identify and obtain mRNA transcripts present in the
15 melanoma cell which encode the p97 antigen; (b) to identify clones in a cDNA expression library that express peptides or proteins related to the p97 antigen; (c) to purify the p97 antigen in order to prepare additional monoclonal antibodies or antisera for use in the previous two applications; or (d) to identify cells into which the gene for the p97 antigen has been introduced by transfection.

The monoclonal antibodies can also be used to facilitate structural and immunochemical characterization
20 of the p97 antigen, so as to identify extracellular and antigenic domains of the molecule, and to purify the molecule for amino acid sequence analysis (Brown et al., 1981, Proc. Natl. Acad. Sci. USA 78:539-543; Brown et al., 1982, Nature, London, 296:171-173).

Further characterization of p97 involves determination of cellular localization and mapping antigenic deter-minants and functional domains. Subcellular localization can be determined by immunofluoresence micro-
25 scopy and by cellular fractionation experiments. Antigens such as p97 that are present on the cell surface are preferred for vaccine construction, although intracellular antigens may also be useful. If multiple monoclonal antibodies are available, antigenic determinants can be mapped by competition experiments, in which each antibody is radiolabeled and tested for competition with each of the other antibodies. Domains of the mole-cule can be identified by limited digestion with proteases followed by SDS-PAGE. Together these data should
30 allow identification of regions of the molecule that are most immunogenic. If the monoclonal antibodies were obtained by immunization with intact cells, then these regions of the molecule are most likely to be extracellular and to be useful for vaccine construction.

Amino acid sequence analysis allows unambiguous identification of the protein and its comparison with other proteins (Brown, et al., 1982, Nature, London, 296:171-173). If the protein comprises more than 50
35 amino acid residues, it may be feasible to determine only a part of the amino acid sequence, most often the N-terminus. Protein antigen for amino acid sequencing can be purified from cell lysates by immunoaffinity chromatography with the monoclonal antibody, followed by preparative SDS-PAGE. The N-terminal amino acid sequence of the purified protein is then determined by using an automatic amino acid sequencer, prefer-ably a gas-phase machine for greater sensitivity.
40

5.1.2 Identification, cloning and sequencing of DNA coding for the melanoma associated p97 antigen

Early cloning studies concentrated on abundant proteins such as globin and ovalbumin, whose mRNAs often comprised 10 to 50% of total mRNA. These mRNAs could be purified to homogeneity by size fractiona-tion, and pure cDNA probes were used to screen libraries of a few hundred clones by colony hybridization.
45 For proteins whose mRNAs comprise 1 of 10% of total mRNA, differential hybridization with two cDNA probes can be used, in which one of the cDNA probes contains the sequence of interest, and the other is a negative control. Messenger RNAs coding for low-abundance proteins, such as tumor-associated antigens, which may comprise as little as 0.01% of cellular mRNA, are much more difficult to clone, because tens of thousands of clones must be screened, and cDNA probes will not give a specific hybridization signal. Both
50 problems can be alleviated by enriching the mRNA for the sequence of interest.

Several approaches used to clone DNA coding for human melanoma associated p97 antigen are described below. The resulting clones were analyzed in order to identify a clone or clones that spanned the entire coding region of p97. The p97 nucleotide inserts of the clones so identified can then be sequenced by any method known in the art. The various approaches are described in more detail below.
55

(a) Isolation of mRNA by polysome immunopurification

In this technique, polysomes (which consist of mRNA, ribosomes and nascent polypeptide chains) are purified by immunoaffinity chromatography with antibodies that recognize antigenic determinants present on the nascent chains. In many cases monoclonal antibodies obtained by immunization with intact cells or
60 cell extracts recognize the antigens in their native conformations, but they may not be appropriate for poly-some immunopurification, since there is a significant chance that the antigenic determinants recognized may not be present in nascent chains. Since translation starts at the N-terminus of the polypeptide, epitopes close to the C-terminus are likely to be absent from the majority of the nascent chains. This problem is avoided either by using antibodies that recognize N-terminal epitopes, or by preparing polysomes from cells
65 treated with a protein synthesis inhibitor that blocks termination.

Proteins and peptides can be produced in large amounts by inserting nucleotide coding sequences into an appropriate expression vector, which is in turn introduced into suitable host cells, including, but not restricted to, bacteria, yeast, insect cells, and mammalian cells. Although bacterial hosts have many advantages, they do not process many eukaryotic cells for the expression of tumor-associated proteins. However, recom-
5 binant proteins produced in bacteria may be useful for induction of T-cell responses, since such responses are believed to require the initial degradation of the protein antigen.

In order to express p97 related peptides in a vector-host system, nucleotide sequences coding for the melanoma associated p97 antigen or a portion thereof, are inserted into an appropriate expression vector. Such nucleotide sequences include but are not limited to all or part of the DNA sequence of p97 substantially
10 as depicted in Figure 3 including altered sequences in which one or more codons within the sequence is substituted by a codon which encodes the same or a functionally equivalent amino acid residue, thus, resulting in a neutral or silent change in the sequence. The expression vector contains the necessary elements for the transcription and translation of the inserted protein-coding sequence. These elements vary in their strength and specificities. Depending on the host-vector system utilized, any one of a number of suitable
15 transcription and translation elements may be used. For instance, when cloning in mammalian cell systems, promoters isolated from the genome of mammalian cells (e.g. mouse metallothionein promoter) or from viruses that grow in these cells (e.g. vaccinia virus 7.5K promoter) may be used. Promoters produced by recombinant DNA or synthetic techniques may also be used to provide for transcription of the inserted sequences.
20 Specific initiation signals are also required for efficient translation of inserted protein coding sequences. These signals include the ATG initiation codon and adjacent sequences. In cases where either the gene or cDNA sequence is inserted into an appropriate expression vector, no additional translational control signals may be needed. However, in cases where only a portion of the coding sequence is inserted, exogenous translational control signals, including the ATG codon may have to be provided. The initiation codon must
25 furthermore be in phase with respect to the reading frame of the protein coding sequences to ensure translation of the entire insert. These exogenous translational control sequences and initiation codons may be of a variety of origins, both natural and synthetic.

Any of the methods known to those skilled in the art for the insertion of DNA fragments into a vector may be used to construct expression vectors containing a chimeric gene consisting of appropriate transcriptional
30 and translational control signals and the protein coding sequences. These methods may include those used in vitro recombinant DNA techniques, synthetic techniques and in vivo recombinations (genetic recombination).

Expression vectors include, but are not limited to the following vectors and their derivatives: vaccinia virus, adenoviruses, insect viruses, yeast vectors, bacteriophage vectors, and plasmid DNA vectors. The
35 cloning and expression of genes in bacterial systems is well known in the art. For instance, when cloning in an E. coli, its bacteriophages or plasmid promoters such as the lac promoter, trp promoter, recA promoter, ribosomal RNA promoter, the P_R and P_L promoters of coliphage lambda and others including but not limited to lacuv5, trp-lacuv5 (tac) hybrid promoter, ompF, bla, lpp and the like may be used to direct high levels of transcription of adjacent DNA segment. However, due to the processing differences between prokaryotic and
40 eukaryotic cells, it may be preferable to express the p97 related peptides of the present invention in eukaryotic cells. The best established methods of expressing proteins in eukaryotic cells are (a) introduction of the gene into the cell together with a drug resistance gene followed by selection with drug, preferably obtaining amplification as with the dihydrofolate reductase-methotrexate system; (b) expression of cDNA in a plasmid vector, often based upon pBR322, using a strong eukaryotic promoter and other regulatory sequences; (c)
45 expression of cDNA in a viral vector, often derived from SV40, again using strong promoters, in this case an SV40 promoter. Recombinant plasmid vectors are often used to produce cell lines that produce the protein over a long period of time, whereas SV40 vectors are often used to obtain transient expression. Although mammalian cells have most often been used as hosts, insect cells, and in some cases yeast cells, may also be suitable. Some are described in more detail below.
50 In order to construct a recombinant vaccinia virus expressing the melanoma associated p97 antigen, the cDNA coding sequence can be ligated to the 7.5K promoter of vaccinia virus to form a chimeric gene. This chimeric gene is flanked by additional vaccinia viral sequence homologous to the viral thymidine kinase gene, which is carried on the plasmid DNA vector. The construction of the chimeric gene involves the use of both natural and synthetic control signals for transcription and translation of the tumor-associated antigen
55 sequence. The chimeric gene is then introduced into vaccinia virus expression vectors through in vivo recombination between the homologous thymidine kinase region present on both the plasmid vector and the vaccinia virus genome. These recombinant viruses containing the chimeric gene are capable of directing the expression of p97 related peptides in an infected host and can be used as components of a vaccine.

In cases where an adenovirus is used as an expression vector, the DNA sequence of interest is ligated to an
60 adenovirus transcription/translation control complex, e.g., the late promoter and tripartite leader sequences. This chimeric gene is then inserted in the adenovirus genome by in vitro or in vivo recombination. Insertion in a non-essential region of the viral genome (e.g., region E1 or E3) will result in a recombinant virus that is viable and capable of expressing the p97 related peptide in infected hosts. Presently, there are two strains of adenovirus (types 4 and 7) approved and used as vaccines for military personnel. They are prime candidates
65 for use as vectors to express the inserted DNA sequence.

9

roach, therefore, which can be used to obtain cDNA clones for tumor-associated proteins such as p97, is to
prepare a cDNA library by reverse transcribing the mRNA (enriched or unenriched) isolated from melanoma
cells as described above, using oligo(T)-nucleotide primers or the synthetic oligonucleotide primers descri-
bed above, and to screen such a library with a monoclonal antibody directed against the melanoma associa-
5 ted p97 protein. Clones that contain DNA coding for the epitopes recognized by the monoclonal antibody in
the correct orientation and reading frame will express peptides or proteins related to the melanoma associa-
ted p97 protein and can be identified by transferring the proteins expressed by the clones to a nitrocellulose
filter and incubating the filter with the antibody, followed by development with a labeled anti-
immunoglobulin reagent.
10   A potential problem is that many monoclonal antibodies fail to recognize the protein expressed by the
bacteria because, in many cases, only a part of the cDNA will be contained in the insert and bacteria do not
process proteins in the manner in which eucaryotic cells do. This problem is particularly acute for tumor cell
surface proteins, which are modified more extensively by removal of the signal peptides, addition of car-
bohydrate side chains, and formation of disulfide bridges. It may therefore be necessary to generate mono-
15 clonal antibodies that are known to recognize the denatured antigen or to prepare polyspecific antisera by
immunization with purified antigen.
     Once a recombinant virus or plasmid that is believed to contain a cDNA insert derived from a melanoma
associated p97 antigen is identified, the cDNA insert can be used to screen additional libraries in order to
identify either full-length clones or else a group of clones that span the full length of the cDNA that codes of
20 p97. The identity of the cDNA cloned can be established by sequence analysis and comparison of the ded-
uced N-terminal amino acid sequence with that determined by direct amino acid sequence analysis of the
p97 protein.

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(d) Genomic cloning
25 · The following method allows cloning of DNA using a monoclonal antibody directed against an antigenic
determinant that is present only in the native protein and is not present in nascent chains or in protein
expressed in bacteria. To this end DNA derived from the human melanoma cell is introduced in mouse L cells
by transfection. Subsequently, mouse cells that express melanoma associated p97 antigen are isolated
either by using the fluorescence-activated cell sorter or by the immunological identification of colonies that
30 produce p97 related peptides using radiolabeled monoclonal antibodies directed against p97 to detect rela-
ted peptides on replicas of colonies transferred to polyester cloth filters. Several subsequent rounds of trans-
fection may be required to remove unrelated human DNA sequences. A genomic library is then prepared in a
lambda phage vector and screened for clones containing human repetitive sequences which occur in the
introns of most genes. Once a genomic clone is identified it can be used as a hybridization probe to identify
35 cDNA clones containing the DNA coding for p97.

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5.2. Synthesis of antigenic fragments of the melanoma-associated p97 antigen and evaluation of im-
munogenicity
     Synthetic peptides can be used as immunogens to elicit an immune response against the native protein
40 that can provide a degree of protection against a number of pathogens. Such peptide sequences are selected
from the known amino acid sequence of the protein antigen by identifying stretches of amino acids that are
likely to be present on the surface of the protein molecule, exposed to the external medium. This is most
commonly achieved by computer analysis of the amino acid sequence using established hydropathy para-
meters for the amino acids. Additional criteria such as the predicted secondary structure or flexibility may
45 also be used.
     Accordingly, synthetic peptides comprising 5 to 50 amino acid residues of the melanoma associated p97
protein may be tested for immunogenicity in experimental animals (usually mice of rabbits). Such synthetic
peptides include but are not limited to all or part of the amino acid sequence substantially as depicted in
Figure 3 including altered sequences in which functionally equivalent amino acid residues are substituted for
50 residues within the sequence resulting in a silent change and/or modified or processed sequences such as
glycosylated sequences, phosphorylated sequences etc., or chemically modified sequences. These p97 rela-
ted peptides are used either alone or coupled to a carrier protein, such as keyhole limpet hemocyanin (KLH).
In either case use of an adjuvant is optional, though preferable. The immunized animals are boosted and
tested for antibodies directed against the immunizing peptide. Those with anti-peptide antibodies are tested
55 for antibodies that bind the native p97 protein. In the case of tumor-associated antigens such as p97 it is also
of interest to test for a cellular immune response, for example, by looking for delayed-type hypersensitivity
(DTH), for an antigen stimulated proliferation in vitro, for cytolytic T-cells, or for tumor rejection in an app-
ropriate model. An appropriate model would be a mouse tumor expressing the human tumor-associated
antigen as result of transfection with an appropriate cDNA expression vector construct.
60   The goal is to identify peptides that elicit a vigorous immune response directed against the melanoma-
associated p97 antigen. Once identified, these peptides may be produced in large quantities by chemical
synthetic methods known in the art. Alternatively, the identified peptides may be produced in large quantities
by expressing the nucleotide sequences that code for such peptides in expression vector-host cell systems.

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65 ### 5.3. Production of p97-related peptides by expression vector-host systems

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The affinity-purified antigen may be purified further by HPLC.

5.4. Immunological characterization of p97-related peptides

The ability of the synthetic or recombinant antigen to elicit an antitumor response can be evaluated initially
in experimental animals. This is achieved by constructing a model system in which the human melanoma-
associated p97 protein is expressed in cells of the appropriate inbred strain of the experimental species.
Animals are then immunized with the p97-related peptide of the present invention by various protocols and
then tested for the development of antibodies directed against the melanoma-associated p97 antigen, for
cell-mediated immunity such as delayed-type hypersensitivity to the p97 antigen, and for their ability to reject
a challenge of viable, syngeneic tumor cells expressing the p97 antigen. In addition, in vitro assays of cellular
immunity can be done to measure proliferation of lymphocytes in response to the p97 related peptide and the
ability of lymphocytes from immunized animals, or human melanoma patients, to kill tumor cells expressing
the p97 antigen. Moreover, by immunizing mice with mouse p97, one is able to determine the extent to which
it is possible to induce an immune response to an antigen that is present in trace amounts in normal tissues.

Non-human primates may be used to establish the safety of the p97-related peptides of the present inven-
tion. To this end the animals can be immunized using protocols that could ethically be applied to human
cancer patients, and then tested as described above, except that the tumor transplantation experiments will
not be feasible, as these require the use of inbred strains. The safety of the immunization procedure is
determined by looking for the effect of the immunization on the general health of the immunized animals
(weight changes, fever, appetite, behaviour, etc.) and looking for pathological changes on autopsy.

Finally the p97-related peptide of the present invention can be tested in human cancer patients. After initial
phase I testing in advanced cancer patients, to establish lack of toxicity, cancer patients in remission but with
a high probability of recurrence could be tested. Their immune response would be evaluated as described
above for non-human primates, except that the effect of the treatment on established disease or on the
frequency of recurrence will be examined. In the case of the melanoma antigen p97 benign nevi (moles),
which express the antigen, will also be examined.

5.5. Formulation of a vaccine

The purpose of this embodiment of the invention is to produce, by synthetic or recombinant DNA tech-
niques, a synthetic peptide, a purified protein, or a recombinant virus that may be used as an immunogen
and a vaccine to protect cancer patients at high risk of recurrence of their disease, to treat established dis-
ease, and ultimately to vaccinate high-risk individuals prophylatically. In fact, the synthetic or recombinant
melanoma-associated p97 antigen may be used in combination with other immunogens to prepare multiva-
lent vaccines for the prevention of melanoma and other cancers. Examples of various vaccine formulations
are discussed below.

5.5.1. Viral vaccine formulations

When the p97-related peptide of the present invention is produced by a recombinant virus, either a live
recombinant viral vaccine or an inactivated recombinant viral vaccine can be formulated. The choice dep-
ends upon the nature of the recombinant virus used to express the p97 related peptide. Where the recombi-
nant virus is infectious to the host to be immunized but does not cause disease, a live vaccine is preferable
because multiplication in the host leads to a prolonged stimulus of similar kind and magnitude to that occur-
ring in natural subclinical infections and, therefore, confers substantial long-lasting immunity. The infectious
recombinant virus, upon introduction into a host, can express the p97-related peptide from its chimeric gene
and thereby stimulate an immune response. The live recombinant virus by itself may be used as a preventat-
ive vaccine against melanoma. Production of such recombinant virus to be used in these formulations may
involve both in vitro (e.g. tissue culture cells) and in vivo (e.g. natural host animal such as cows) systems.
Conventional methods for the preparation and formulation of smallpox vaccine may be adapted for the
formulation of live recombinant virus vaccine.

Multivalent live virus vaccines can be prepared from a single or few infectious recombinant viruses that
express a variety of antigens of different tumor or cancer cells. For example, a vaccinia virus (which can
accommodate approximately 35 kilobases of foreign DNA) can be engineered to contain coding sequences
for other epitopes; such a recombinant virus itself can be used as the immunogen in a multivalent vaccine.
Alternatively, a mixture of vaccinia and/or other viruses, each capable of directing the expression of a dif-
ferent gene coding for different epitopes can be formulated in a multivalent vaccine.

Whether or not the recombinant virus is infectious to the host to be immunized, an inactivated vaccine
formulation may be prepared. Inactivated vaccines are "dead" in the sense that their infectivity has been
destroyed, usually by treatment with formaldehyde. Ideally, the infectivity of the virus is destroyed without
affecting the capsid or envelope proteins which carry the immungenicity of the virus. In order to prepare
inactivated vaccines, large quantities of the recombinant virus must be grown in culture in order to provide
the necessary quantity of relevant antigens. A mixture of inactivated viruses which express different epitopes
may be used for the formulation of "multivalent" vaccines. In some instances this may be preferable to live
vaccine formulations because of potential difficulties with mutual interference of live viruses administered
together. In either case, the inactivated recombinant virus or mixture of viruses should be formulated with a
suitable adjuvant in order to enhance the immunological response to their antigens. Suitable adjuvants

An alternative expression system which could be used to express the p97 related peptides is an insect system. In one such system, *Autographa californica* nuclear polyhedrosis virus (AcNPV) is used as a vector to express foreign genes. The virus grows in *Spodoptera frugiperda* cells. The DNA sequence of interest can be cloned into non-essential regions (for example the polyhedrin gene) of the virus and are placed under control of an AcNPV promoter (for example the polyhedrin promoter). Successful insertion of the DNA sequence will result in inactivation of the polyhedrin gene and production of non-occluded recombinant virus (*i.e.*, virus lacking the proteinaceous coat coded for by the polyhedrin gene). These recombinant viruses are then used to infect *Spodoptera frugiperda* cells in which the inserted gene is expressed.

In addition, host cell strains may be chosen which modulate the expression of the inserted sequences, or modify and process the chimeric gene product in a specific fashion desired. Expression from certain promoters can be elevated in the presence of certain inducers (*e.g.* zinc and cadmium ions for metallothionein promoters). Therefore, expression of the genetically engineered protein may be controlled. This is important if the protein product of the cloned gene is lethal to the host cells. Furthermore, modifications (*e.g.*, glycosylation, phosphorylation, etc.) and processing (*e.g.*, cleavage) of protein products are important for the structure and function of the protein. Different host cells have characteristic and specific mechanisms for the post-translational processing and modification of proteins. Appropriate cell lines or host systems can be chosen to ensure the correct modification and processing of the foreign protein expressed.

In the particular embodiment described herein for p97, we ligated the p97 cDNA sequence into an expression plasmid vector derived from pBR322 which contains the metallothionein promoter. The entire coding sequence of p97 including the signal peptide and the membrane anchor was inserted into the vector.

5.3.1. *Identification of recombinant expression vectors capable of replicating and directing the expression of the p97 DNA sequences*

Expression vectors containing foreign gene inserts can be identified by three general approaches: (a) DNA-DNA hybridization, (b) presence or absence or marker gene functions, and (c) expression of inserted sequences. In the first approach, the presence of a foreign gene inserted in an expression vector can be detected by DNA-DNA hybridization using probes comprising sequences that are homologous to the foreign gene insert. In the second approach, the recombinant vector/host system can be identified and selected based upon the presence or absence of certain "marker" gene functions caused by the insertion of genes in the vector (*e.g.* thymidine kinase activity, resistance to antibiotics, transformation phenotype, etc.). For example, if the foreign gene is inserted within the marker gene sequence of the vector, recombinants containing the DNA insert can be identified by the absence of the marker gene function. In the third approach, recombinant expression vectors can be identified by assaying the foreign gene product expressed by the recombinant. Such assays can be based on the physical, immunological, or functional properties of the gene product.

For example, when constructing a recombinant vaccinia virus according to the present invention, the chimeric gene containing the p97 coding sequences is inserted into the thymidine kinase gene, thereby inactivating and endowing on the virus a TK$^-$ phenotype. Such recombinants are selected by their ability to grow in media containing 5-bromo-deoxyuridine a nucleoside analog that is lethal to TK$^+$ cells but not TK$^-$ cells. The recombinants are further identified by DNA-DNA hybridization, using a cDNA probe specific for the tumor-associated protein. TK$^-$ recombinant virus can be isolated by plaque-purification and stocks are prepared from infected cultured cells. The recombinant virus can be tested for its ability to induce synthesis of the p97 related peptides. To this end, infected cells can be grown in the presence of radiolabeled amino acids; then lysates and subcellular fractions of the infected radiolabeled cells are tested by immunoprecipitation with antibodies directed against the native melanoma associated p97 antigen. The immunoprecipitated products are resolved by SDS-PAGE. Infected cells can also tested by immunofluorescence using monoclonal antibody.

Cells into which a plasmid vector has been introduced by transfection can readily be identified by FACS analysis or by binding assays of replicas of cell colonies on polyester cloth. The amount of p97-related peptide present can be determined by a quantitative radioimmunoassay, and its subcellular localization can be determined by cellular fractionation and by immunofluorescence microscopy. The structure of the p97 related peptide expressed can be determined by SDS-PAGE and by amino acid sequence analysis.

5.3.2. *Purification of the p97-related peptide from expression vector-host systems*

Many tumor-associated antigens such as p97 are cell-surface glycoproteins and contain an N-terminal signal peptide and a C-terminal anchor peptide (Davis et al., 1985, J. Mol. Biol. 181: 111-121). When expressed on an appropriate vector it is expected that the protein will be translocated to the cell surface. To facilitate purification of the protein it may be preferable to delete the DNA sequence coding for the membrane anchor region, so that the mature protein is released into the culture medium.

The p97 related peptide can be purified from that host cells by detergent lysis followed by affinity chromatography using monoclonal antibodies. If a truncated protein is to be purified from the culture medium it is preferable to use serum-free medium, and then to use affinity chromatography with monoclonal antibodies. It is important that the antigen can be eluted from the antibody adsorbent without either reducing its antigenicity or denaturing it. This may be achieved by raising or lowering the pH or by using a chaotrope. It may be necessary to select a monoclonal antibody that will release the antigen under relatively mild conditions.

colonies of transformed bacteria was bound to paper (Taub & Thompson, 1982, Anal. Biochem. 126:222-230) and screened by differential hybridization with cDNA probes synthesized on p97-enriched and unenriched mRNA templates.

A 243-base pair (bp) clone, p97-3a2fl, was identified, which hybridized to p97-enriched cDNA but not det-
5 ectably to unenriched cDNA and also selected p97 mRNA in hybrid-selected translation experiments. A poly-   5
adenylation signal (AATAA) and a poly(A) tract were present at the 3' end of the cDNA (see Figure 2). Nick translated p97-3a2fl hybridized 100-fold more strongly to p97-enriched mRNA than to unenriched melanoma mRNA, and not detectably to fibroblast mRNA. Northern blot analysis with the cloned cDNA as a probe identified an mRNA of approximately 4 kilobase (kb), which was present in SK-MEL 28 melanoma cells and
10 absent from fibroblasts.   10

6.2.2.   Genomic cloning of p97 and the use of synthetic oligonucleotides to prime cDNA synthesis
Attempts to obtain cDNA clones extending more than 1 kb from the polyadenylation site were unsuccess-
ful, possibly due to a region of high GC content (greater than 80%) with extensive secondary structure.
15 Genomic cloning was used to circumvent this problem. Four overlapping genomic clones were isolated from   15
libraries of lambda L47.1 containing size-fractionated SK-MEL 28 DNA enriched for a specific p97 restriction fragment. These four genomic clones span 28kb and contain the entire coding region of p97 including the regulatory region of the gene. The genomic clones as arranged sequentially from 5' to 3' are: lambda B15, lambda H17, lambda B6.6, and lambda E7.7. The nomenclature consists of a letter which refers to the restric-
20 tion enzyme used to generate the fragment and the numeral indicating the kilobase size of the fragment   20
which was cloned into lambda L47.1. Thus, starting from the 5' terminus, lambda clone B15 contains a 15kb BamHI p97 fragment; lambda clone B17 contains a 17kb HindIII p97 fragment; lambda clone B6.6 contains a 6.6kb BamHI p97 fragment; and lambda clone E7.7 contains a 7.7kb EcoRI p97 fragment (see Figure 2A). Restriction fragments of the clones that hybridized to the 4 kb p97 mRNA on Northern blots were sequenced
25 and p97 exons were identified by a computer assisted homology search between the predicted coding   25
sequences and the amino acid sequence of human and chicken transferrin (Yang et al., 1984, Proc. Natl. Acad. Sci. USA 81:2752-2756; McGillivray et al., 1982, Proc. Natl Acad. Sci. USA 79:2504-2508; Jetsch & Chambon, 1982, Eur. J. Biochem. 122:291-295).

Three synthetic oligonucleotides, the sequence of which were based on p97 genomic exon sequences,   30
30 were used to prime cDNA synthesis on SK-MEL 28 mRNA and the resulting cDNA was cloned into lambda-
gt10 as follows: the p97 cDNA was dG-tailed and ligated with a bridger oligonucleotide (AATTCCCCC-
CCCCCC) and lambda-gt10 which had been restricted with EcoRI. The bridger oligonucleotide permitted insertion and ligation of the dG-tailed cDNA sequence into the EcoRI site of lambda gt10. The lambda phage was packaged (Grosveld et al., 1981, Gene 13:227-237), and plated on E. coli c_{600} rK⁻ mK⁺hfl. The cDNA
35 libraries in lambda-gt10 were screened for the p97 insert by plaque hybridization (Benton & Davis, 1977,   35
Science 196:180) with genomic exon fragments as probes. Probes were radiolabeled with ³²P-TTP (New England Nuclear, 3200 Ci/mmole) by nick-translation to a specific activity of 5-10 = 10⁸ cpm/μg. Three over-
lapping cDNA clones (10al, 1jl, 2fl) spanning 2,368 nucleotides of the p97 mRNA, including the entire coding region, were identified by using p97 exon specific fragments as probes (Figure 2).   40
40

6.3.   DNA sequence analysis of p97
cDNA inserts were excised and subcloned into plasmid vector pEMBL18+ (Dente et al., 1983, Nucleic Acids Res. 11:1645-1655) in E. Coli for subsequent propagation and restriction mapping. cDNA was also subcloned into M13mp18 phage cloning vector (Yanish-Perrone et al., 1985, Gene 33:103-119) and sequenced using the   45
45 dideoxy method of Sanger (Sanger et al., 1977, Proc. Natl. Acad. Sci. USA 74:5463-5467). M13 clones contain-
ing large inserts were sequenced by generating deletions using DNAse I (Hong, 1982, J. Mol. Biol. 158:539-
549) or exonuclease III (Henikoff, 1984, Gene 28:351-359), and by using synthetic 21-mer oligonucleotide primers.

The p97 cDNA sequence is shown in Figure 3. An open reading frame of 2,214 nucleotides extends from the   50
50 first ATG, the sequence around which conforms with the consensus initiation sequence determined by Kozak
(Kozak, 1980. Nucleic Acids Res. 8:127-142), to the TGA at position 2,215. The most 5' cDNA clone contains an additional 60 nucleotides upstream of the initiating ATG. The 3' non-coding region of p97 mRNA, which was not obtained as a cDNA clone, was identified as a single genomic exon containing 1,667 nucleotides. Re-
sidues 20-32 of the predicted amino acid sequence are identical to the known N-terminal amino acid sequ-   55
55 ence of p97 (Brown et al., 1982, Nature, London 296:171-173), proving the identity of the cloned cDNA.
Furthermore, the predicted molecular weight of the precursor is 80,196 daltons, in good agreement with the observed molecular weight of the in vitro translation product.

6.4.   Construction of a recombinant expression plasmid containing the p97 coding sequence   60
60 The large size of the p97 gene necessitated piecing together the cDNA clones that were obtained by specific
priming of melanoma mRNA with reverse transcriptase. The three cDNA lambda gt10 clones (10al, 1jl, and 1fl; see Figure 2) that encompassed the coding region from the signal peptide through the membrane anchor sequence were used. The p97 insert of clone 10al was excised by digestion with EcoRI and the oligo(dG) sequence at the 5' end of the cDNA 10al was removed by digestion with exonuclease III, generating clone
65 10alb, with a HindIII site 30 bp upstream from the initiating methionine of the p97 preprotein. The p97 inserts   65

include, but are not limited to, mineral gels, *e.g.* aluminum hydroxide; surface active substances such as
lysolecithin; pluronic polyols; polyanions; peptides; and oil emulsions.
    Many methods may be used to introduce the vaccine formulations described above; these include but are
not limited to intradermal, intramuscular, intraperitoneal, intravenous, subcutaneous and intranasal routes.
5 When a live recombinant virus vaccine formulation is used, it may be introduced via the natural route of   5
infection of the parent wild type virus which was used to make the recombinant virus in the vaccine formula-
tion.

5.5.2. *Subunit vaccine formulations*
10   In an alternative to viral vaccines, the p97-related peptide itself may be used as an immunogen in subunit   10
vaccine formulations. Subunit vaccines comprise solely the relevant immunogenic material necessary to
immunize a host. Accordingly, the p97-related peptide may be purified from recombinants that express the
peptide. Such recombinants include any of the previously described virus-infected cultured cells, bacterial
transformants, or yeast transformants. In another embodiment of the present invention, the p97-related
15 peptides or proteins may be chemically synthesized.   15
    Whether the p97-related peptides are purified from recombinants or chemically synthesized, the final pro-
duct may be adjusted to an appropriate concentration and formulated with any suitable vaccine adjuvant and
packaged for use. Suitable adjuvants include, but are not limited to: Mineral gels, *e.g.,* aluminum hydroxide;
surface active substances such as lysolecithin; pluronic polyols; polyanions; peptides; and oil emulsions.
20 The p97-related peptide may also be incorporated into liposomes, or conjugated to polysaccharides and/or   20
other polymers for use in a vaccine formulation.
    In instances where the p97-related peptide is a hapten, *i.e.,* a molecule that is antigenic in that it can react
selectively with cognate antibodies, but not immunogenic in that it cannot elicit an immune response, the
hapten may be covalently bound to a carrier or immunogenic molecule and the hapten-carrier may be formu-
25 lated for use as a vaccine; for instance, a large protein such as protein serum albumin will confer im-   25
munogenicity to the hapten coupled to it.

6. *Example: Melanoma associated p97 antigen*
    In the example described below, cDNA clones derived from various regions of p97 mRNA were pieced
30 together and inserted into an expression vector which directs the expression of a peptide related to p97. The   30
p97-related peptides produced by the expression vector-host cell may be formulated in a vaccine.

6.1. *Purification of p97 mRNA*
    Polysomes were prepared from SK-MEL28 melanoma cells (Carey et al., 1976, Proc. Natl. Acad. Sci. USA
35 73:3270-3282) by magnesium precipitation. From this preparation polysomes bearing p97 nascent chains   35
were purified by incubation with 3 IgG2a monoclonal antibodies (96.5, 118.1. 133.2) specific for distinct
epitopes of p97 (Brown et al., 1980, J. Biol. Chem. 255:4980-4983; Brown et al., 1981, J. Immunol. 127:539-
546; Brown et al., 1981, Proc. Natl. Acad. Sci. USA 78:539-543; Plowman et al., 1983, Nature, London 303:70-
72) followed by affinity chromatography on protein A sepharose. The p97-enriched mRNA was eluted using
40 EDTA and purified by affinity chromatography on oligo(T)-cellulose (Bethesda Research Labs, Bethesda MD).   40
In a typical experiment, 150 E_{260} units of polysomes yielded 260 ng p97-enriched mRNA, which represents
0.23% of the total mRNA. When translated in *Xenopus* oocytes and assayed for p97 as described (Brown et al.
1981, Proc. Natl. Acad. Sci. USA 78:539-543; Plowman et al., 1983, Nature, London 303:70-72), p97-enriched
mRNA yielded 80 pg p97 per ng mRNA, whereas p97-unenriched mRNA yielded only 0.44 pg p97 per ng
45 mRNA, showing that p97 mRNA activity had been enriched 180-fold. The yield of p97 mRNA activity was 42%.   45
Translation in the reticulocyte lysate system (Pelham & Jackson, 1976, Eur. J. Biochem. 67:247-256) showed
that p97-enriched mRNA coded for a major polypeptide with an apparent molecular weight of 84,000 daltons
as analyzed by SDS-PAGE which was not detectable in the translation products of unenriched mRNA, and
was immunoprecipitated by antiserum specific for p97 (Figure 1). We concluded that this was the un-
50 glycosylated precursor of p97.   50

6.2. *Preparation and construction of cDNA clones*
    Two techniques described below were used to construct cDNA clones transcribed from the mRNA tem-
plates isolated above.
55   55
6.2.1. *Construction of cDNA clones primed by oligo(T)*
    The p97-enriched mRNA prepared above was used as template for oligo(T)-primed cDNA synthesis. The
cDNA was cloned in pBR322 as follows: for first strand cDNA synthesis, p97-enriched mRNA, and four dNTPs
and oligo(T) (Collaborative Research, Walthma, MA) were incubated with reverse transcriptase (Molecular
60 Genetic Resources). The second strand was synthesized by incubation with the large fragment of *E. coli* DNA   60
polymerase (Bethesda Research Labs, Bethesda MD), and the double stranded cDNA was digested with SI
nuclease (gift from D. Durnam of the Fred Hutchinsen Cancer Research Center, Seattle, WA). The cDNA was
then dC-tailed with terminal deoxynucleotidyl transferase (Bethesda Research Labs, Bethesda, MD), an-
nealed with *Pst*I-digested, dG-tailed pBR322 (Bethesda Research Labs, Bethesda, MD) (Villa-Komaroff et al.,
65 1978, Proc. Natl. Acad. Sci. USA 75:3727-3731) and used to transform CaCl$_2$-treated *E. coli* RR1. DNA from   65

A search of the amino acid sequence library of the Protein Identification Resource (Release 5.0; Dayhoff et al., 1981, Nature, London 290:8) showed that p97 is strikingly homologous to three members of the transferrin superfamily: human serum transferrin, human lactotransferrin and chicken transferrin (37%-39% homology, see Figure 4). Since human and chicken transferrin show 50% homology to each other, p97 must have

5   diverged from serum transferrin more than 300 million years ago. p97 has 14 cysteine residues located in homologous positions in each domain. Human transferrin contains all of these cysteines in homologous positions in both domains, while human lactrotransferrin and chicken transferrin lack only two of these cysteine residues (in their C-terminal domains). Unlike p97, these proteins contain 4-7 additional cysteines in their C-terminal domains which have no corresponding member in the N-terminal domain. Human transferrin also contains 2 extra cysteines unique to its N-terminal domain. The positions of most of the disulfides

10   ferrin also contains 2 extra cysteines unique to its N-terminal domain. The positions of most of the disulfides in human serum transferrin, lactotransferrin and chicken transferrin have been determined directly (McGillivray et al., 1982, Proc. Natl. Acad. Sci. USA 79:2504-2508; Metz-Boutigue et al., 1984, Eur. J. Biochem. 145:659-676; Mazurier et al., 1983, Experientia (Basel) 39:135-141; MacGillivray et al., 1983, J. Biol. Chem. 258:3543-3553; Williams et al., 1982, Eur. J. Biochem. 122:297-303; Williams, 1974, Biochem J. 141:745-752).

15   One can thus predict the presence of 7 disulfide bonds in each domain of p97 (see Figure 5).
The amino acid homology between domains of p97 (46% - achieved by insertion of 7 gaps of 9 residues) is more striking than that seen in human transferrin (43% - 16 gaps, 45 residues) or chicken transferrin (35% - 12 gaps, 49 residues). Given the extensive sequence homology between p97 and transferrin, and the apparently similar folding patterns, based upon the conservation of cysteines, we believe that if the present low-

20   resolution X-ray structure of transferrin (Gorinsky et al., 1979, Nature, London 281:157-158) can be refined it may be possible to deduce the three-dimensional structure of p97.

6.6.3.   Function of p97
Its membership in the transferrin superfamily, its ability to bind iron (Brown et al., 1982, Nature London 296:171-173), and its common chromosomal localization with transferrin and the transferrin receptor (Plow-

25   man et al., 1983, Nature, London, 303:70-72; Yang et al., 1984, Proc. Natl. Acad. Sci. USA 81:2752-2756) all support a role of p97 in iron transport. The iron binding pocket of transferrin is thought to contain 2-3 tyrosines, 1-2 histidines and a single bicarbonate-binding arginine (Metz-Boutigue et al., 1984, Eur. J. Biochem. 145:659-676). Conservation of these amino acids in p97 support its proposed role in iron metabolism (see Figure 4). Since p97 is a membrane bound transferrin-like molecule and has no homology with the transferrin

30   receptor (Schneider et al., 1984, Nature, London, 311:675-678), its role in cellular iron metabolism may differ from that provided by circulating serum transferrin and the cellular receptor for transferrin. Expression of the cloned p97 cDNA in eukaryotic cells will allow experimental testing of its functional properties.

6.6.4.   Conclusion
35   Based on these data it is clear that cDNA constructs for the melanoma-associated p97 have been obtained and that these can be expressed efficiently in mammalian cells to produce large amounts of antigenic p97.

7.   Expression of cloned p97 and vaccine testing
40   The experiments detailed herein describe the expression of the cloned p97 protein and its vaccine testing. Expression of p97 protein is a secreted form (by the transfected mouse cell clone B16svp97a.14) enabled purification of milligram quantities of the full length p97 protein. The protein in purified form was used for in vitro testing of induction of cellular immunity and for testing its potential as a subunit vaccine. The p97 gene product was also expressed on the cell surface of metastatic murine malanoma cells, providing a model for

45   testing the efficacy of vaccines in preventing tumor growth in a syngeneic system.
The p97 gene was inserted into a live vaccinia recombinant virus for use as a vaccine formulation capable of generating effective cellular immunity. The recombinant vaccinia virus, Vp97a-NY, was evaluated for its ability to generate immunity in mice, using a variety of assays for demonstrating humoral and cellular immunity. Using the syngeneic murine tumor model described supra, the Vp97a-NY recombinant virus vaccine

50   was demonstrated to provide a protective effect from tumor cell challenge. The vaccine also provided a therapeutic effect in mice with existing growing lung metastases, a property which is analogous to the proposed use of the vaccine for generating an immunotherapeutic anti-tumor response in human melanoma patients with existing tumor.
In addition to the mouse studies, where there is only 91% homology between human p97 and the mouse

55   homologous protein (over the regions examined thus far), the Vp97a-NY vaccine has also been tested in non-human primates. There is a much closer homology between human p97 and the monkey form of the protein (as revealed by the cross-reactivity at the monoclonal antibody level). Because of the potential difficulty in generating an immune response against a "self" protein, the closely related Macaque monkey was used to test the immunogenicity of the Vp97a-NY vaccine. The recombinant vaccinia vaccine was tested in

60   monkeys and shown to induce humoral immunity directed against the p97 protein. Thus far the monkeys have exhibited no noticeable symptoms of deleterious side effects from exposure to the vaccine, after having two inoculations of the live recombinant vaccinia virus, over a period of six weeks.

7.1.   Plasmid expression
65   The expression plasmid driven by the SV-40 early promoter sv2 was constructed from the cDNA plasmid

of the three cDNA clones 10alb, 1jl, and 2fl, and genomic clone E7.7 were ligated together at *Pvull*, *Sstl* and *EcoRI* restriction enzyme sites and inserted into the *HindIII*-*EcoRI* sites of the plasmid vector pEMBL18+ (Dente, et al. 1983, Nuc. Acid Res. 11:1645-1655) as shown in Figure 2. The final construct, p97b, contains the 4.4 kb p97 insert in plasmid vector pEMBL18+ which was used to transform *E. coli* HB101. The insert in p97b
5 contains 30 bp of the 5' untranslated region of p97 mRNA, the entire coding sequence, and the 3' untranslated region, bounded by a 5' *HindIII* site and a 3' *EcoRI* site.   5

The 4.4 kilobase p97 insert was excised from p97b with *HindIII* and *EcoRI*, and the ends were filled in using the Klenow fragment of *E. coli* DNA polymerase. The blunt-ended fragment was inserted into the unique *SmaI* site in the eukaryotic cDNA expression vector 1995.12 pUC13, a derivative of vector mThGH-112, (Palm-
10 iter et al., 1983, Science 222:809-14), which was obtained from Dr. Richard Palmiter (University of Washington, Seattle, Washington). This vector uses the mouse metallothionein promoter to express foreign genes in eukaryotic cells. The construct with the p97 insert in the correct orientation was identified by restriction analysis and designated pMTp97b.   10

The recombinant plasmid was transfected into LMTK⁻ cells, and transfectants were selected by growth in
15 HAT medium. Clones picked from the transfected dish were expanded in 96-well microtest plates, and spent culture medium and cell lysates from replicate plates were asasayed for p97 by a two-site immunoradiometric assay. Subclones were expanded and retested. Clone TKMp97-12 which expresses approximately 4,000,000 molecules of p97 per cell was grown up, induced with cadmium, and used as a source of p97 for immunization.   15
20

6.5. *Immunization of mice with p97 related peptides*
The TKMp97-12 cells were grown up, indice with cadmium and (14.4 g) were lysed by incubation for 10 minutes on ice with 70 ml TNEN (20 mM Tris-HCl, pH 8.0, 100 mM NaCl, 1 mM EDTA, 0.5% NP-40). The lysate was ultracentrifuged at 200,000 × g for 45 minutes at 4°C, and half of the lysate was passed over a 1 ml
25 immunoaffinity column specific for p97 (Fab fragment of antibody 96.5 coupled to Sepharose). The immunoadsorbent was washed extensively, first with TNEN, and finally with 20 mM Tris-HCl, pH 6.8.   25

For the immunization, 0.5 ml of the adsorbed immunoaffinity column prepared as described above was mixed with 0.5 ml 20 mM Tris-HCl, pH 6.8, and emulsified with 1 ml complete Freund's adjuvant. Four BALB/c mice each received 0.4 ml of the emulsion intraperitoneally. Three weeks later the mice were boos-
30 ted with one fourth of this amount of antigen in incomplete Freund's adjuvant. Control mice were immunized with an immunoaffinity column of an antibody unrelated to p97 that had been otherwise treated indentically.   30
Four of the p97-immunized mice and two control mice were bled one week after the boost. The sera were tested for antibodies of p97 by immunoprecipitation from radioiodinated SK-MEL meloma cells followed by SDS-PAGE. The results showed that sera from the four p97-immunized mice immunoprecipitated p97,
35 whereas the control sera were negative. The sera were also tested for the presence of antibodies directed   35
against p97 using an ELISA assay on glutaraldehyde-fixed SK-MEL 28 melamona cells (20,000 cells per microtest well). The fixed cells were incubated with 0.05 ml serum diluted 1/10,000 for 1 hour at room temperature, washed, and then incubated for 1 hour at room temperature with 0.05 ml horseradish peroxidase-conjugated goat anti-mouse IgG (Southern Biotech). The optical densities (read at 490 nm) of sera from the
40 p97-immunized mice were 0.350, 0.243, 0.343, 0.200, whereas the optical density of sera from controls were   40
0.036 and 0.057.

6.6. *Characterization of p97*
45
6.6.1. *Structure of p97*   45
45 The structure of p97 was determined from the amino acid sequence of the p97 precursor which comprises four structural domains. Since residue 20 of the precursor sequence corresponds to the N-terminus of mature p97, amino acid residues 1-19 probably constitute a signal peptide, a conclusion that is supported by its length and hydrophobic nature. Amino acids 20-361 and 362-713 comprise two homologous domains of 342
50 and 352 amino acids. Potential N-linked glycosylation sites occur at positions 38 and 135 in the N-terminal   50
domain and position 515 in the C-terminal domain. Finally, we believe that amino acids 714-738, a region of predominately uncharged and hydrophobic residues, anchor p97 in the cell membrane (Davis et al., 1985, J. Mol. Biol. 181:111-121) and may extend into the cytoplasm.

The domain structure of p97 is supported by the protease digestion experiments. Digestion of p97 with
55 trypsin, papain (Brown et al., 1981, J. Immunol. 127:539-546) or thrombin produced a glycosylated, antigenic   55
fragment of approximately 40,000 daltons in molecular weight. The fragment was purified from a thrombin digest of p97 that had been metabolically labelled with ³⁵S-methionine or ³⁵S-cysteine and sequenced as described (Brown et al., 1982, Nature, London 296:171-173). Cysteine residues were identified at positions 7 and 17, and methionine residues at positions 2 and 20. Identical results were obtained with intact p97, and are
60 in complete agreement with the N-terminal sequence of p97 predicted from the cDNA sequence. We con-   60
clude that the 40,000 dalton molecular weight protease-resistant fragment corresponds to the N-terminal domain of p97. We have been unable to isolate the C-terminal domain of p97, possibly because it is protease-sensitive.

65
65   6.6.2   *Homology of p97 with transferrin*   65

ligating into the vaccinia insertion vector pGS-20 (Mackett et al., 1984, J. Virol. 49:857-864) which had been
opened at the Smal site. The PGS-20 vector utilizes the 7.5 K promoter, and contains flanking sequences from
the vaccinia thymidine kinase (TK) gene. A recombinant virus was generated by the method or Mackett et al.,
supra, and Vp97a-NY was isolated which causes infected cells to express p97 protein of the correct size and
5 glycosylation (Figure 8). Surface expression of p97 was also confirmed in cells infected with the recombinant
p97 virus (Table I) below.

Table I

10 Surface p97 expression of transfected mouse cells and cells infected with recombinant vaccinia virus[1]

Cell Type	Virus Used to Infect Cell	Molecules of p97 Expressed per Cell
15 M2SVp97a.A	None	3,210,000
M2svp97a.E/F2	None	434,000
M2 parent	None	2,000−
BSC	None	5,590
BSC	Vwt-NY vaccinia	5,220
20 BSC	Vp97a-NY vaccinia	1,140,000

[1]Cells were trypsinized briefly, washed and aliquoted into tubes containing 10^3, to 10^4 or 10^5 cells. Non-
expressing carrier cells were added to tubes with lower cell numbers so that a total of 10^5 cells were used per
tube. 1×10^6 cpm of iodinated monoclonal antibody 96.5 (123 ng) was incubated, in a total volume of 50 ul,
25 with the cells for 60 minutes on ice. Cells were washed and spun 4 times in PBS + 10% fetal calf serum, then
resuspended and counted in a Micromedic 4/600plus gamma counter.
(−) signifies less than.

7.3.   Recombinant p97 vaccinia virus is immunogenic in mice
30   Inoculation of mice with Vp97a-NY generated a strong humoral antibody response. Mice were immunized
once, boosted once at four weeks, then bled at five weeks. Titers were assessed by ELISA, using antigen-
coated plates and a Protein A conjugated to horseradish peroxidase as detection reagent. Data were conver-
ted to monoclonal antibody equivalents by comparison to a standard curve for ELISA binding generated
using anti-p97 monoclonal antibody 133.2. The results showed a strong induction of serum antibody (Figure
35 9). Cellular immunity was detected using an in vitro proliferation assay with purified p97 protein as the
stimulating antigen (Table II).

Table II

40 Profileration assay of murine spleen cells[1]

Stimulating Antigen	Proliferative Index of vp97 Recombinant Immune Spleen Cells	Proliferative Index of Control Spleen Cells
Con A (10 ug/ml)	71	50
p97 Protein (3 ug/ml)	27	2
50 (10 ug/ml)	43	2
(20 ug/ml)	56	2
(50 microgr/ml)	44	3
UV-Inactivated Vaccinia Virus (10^7 pfu/ml)	91	2
P97-Transfected Irradiated Syngeneic Tumor Cells (10^4)	86	2
Parental Irradiated Tumor Cells (10^4)	3	1

[1]Spleen cells were isolated from mice inoculated by tail scarification with 10^7 pfu Vp97a-NY recombinant
virus, boosted one month later with the same dose and killed one week subsequently. Naive spleen cells
were used for controls in this experiment. 10^5 cells were cultured per well in 96-well round bottom plates in
65 0.22 ml RPMI supplemented with 0.5% normal mouse serum, penicillin/streptomycin, glutamine, bi-

clone p97a, which is similar to plasmid p97b, except that the entire 3'UT region is utilized (Figure 6). All cDNA clones were originally isolated from lambda gt10 libraries with synthetic *Eco*RI-dG (9-17) linkers as previously described. Inserts were excised by *Eco*RI and subcloned into pEMBL18+ for subsequent propagation and characterization. Clone 10al was subcloned into M13mp18 and an RF form was digested with *Bam*HI and
5 *Sph*I, treated briefly with Exonuclease III, blunted with S1 Nuclease, treated with Klenow, and religated. 5 Several plaques were isolated and sequenced, one of which had removed the dG tail and retained 33 bp of the p97 5' untranslated region inserted into the *Hind*III site of M13mp18. An RF of this subclone (10a1a) was used for generating the intact p97 cDNA; otherwise, all fragments were isolated from the plasmid subclones. The 550 bp *Hind*III-*Pvu*II fragment from 10a1a and the 735 bp *Pvu*II-*Sal*I fragment from 1jI were isolated from LMP
10 agarose gels and ligated into pEMBL18+ at the *Sal*I and *Hind*III sites, generating p5'p97. E7.7 genomic clone 10 in pEMBL18+ was digested to completion with *Eco*RI and digested partially with *Sst*I, and the 4.5 kb fragment was separated by fractionation through 0.8% LMP agarose. This 4.5 kb 3' fragment was ligated with the 404 bp *Sst*I fragment from 2fI and the 535 bp *Bam*HI-*Sst*I fragment from 1jI into pEMBL18+ at the *Sal*I and *Eco*RI sites, generating p3'p97. The 1285 bp *Hind*III-*Sal*I fragment of p5'p97 was then ligated into p3'p97, generat-
15 ing pp97a. The *Eco*RI-partial *Hind*III fragment from this clone was inserted into pSV2neo (Southern, et al., 15 1982, J. Mol. App. Genet. 1:327-341) at the *Hind*III and *Eco*RI sites, eliminating the neomycin coding region and SV40 splice/polyA sequences while retaining the SV40 early promoter and 72 bp enhancer, 33 bp p97 5'UTR, the entire p97 coding region, 3' UTR and 1.4 kb 3' flanking DNA. The resulting plasmid was termed pSVp97a.
20 The sv2 driven plasmid was transfected by calcium phosphate precipitation into a variety of eukaryotic cell 20 lines, and expressing cells were cloned and selected using co-transfection of a dominant selectable marker. To accomplish this, Chinese hamster ovary (CHO) cells were cultured in Hank's F1 medium containing 15% fetal calf serum (FCS), 4mM L-glutamine, 1.3 mM proline, and antibiotics. B16 cells were cultured in RPMI medium containing 0.15% bicarbonate and 1735 cells in DMEM medium (Gibco) both supplemented with
25 15% FCS, and antibiotics. Cells were transfected by a modified calcium phosphate technique (Wigler M., et 25 al., 1978, Cell 14:725-731) with 20 ug per plate of pSV2p97a plasmid DNA and 0.5 ug of either pSV2DHFR or pSV2neo respectively. All plasmids were linearized at the *Eco*RI site. Stable transfectants were selected using hypoxanthine negative (HAT−) medium for CHO cells or 0.5 ug/ml Geneticin (G418, Gibco) for the B16 and 1735 cells. Surviving cells began forming visible colonies 7 days after transfection and were overlaid with
30 sterile polyester filters held in place by glass beads. The filters remained in place for five days, allowing the 30 cells to grow up into the polyester matrix, generating a replica of the colonies on the plate. The filters were then removed and used for a live cell binding assay with iodinated anti-p97 monoclonal antibody. Ten micrograms of labeled monoclonal antbody were incubated with up to 20 filters in 10 ml FCS at 4°C for one hour. The filters were washed extensively in phosphate-buffered saline (PBS), dried and exposed to XAR-5 film
35 overnight at −70°C. Filters were subsequently stained with 7% methylene blue to visualize the cell colonies. 35 In all the cell lines used except the B16 mouse line, the expressing cells contained antigenic p97 protein on their cell surfaces.
In the B16-transfected cells, p97 was released into the medium, a finding unique to this cell type. The secretion of p97 enabled purification of full length p97 protein from the medium of the cells. Clone
40 B16SVp97a.14 expressed approximately 4 ug/ml of p97 in spent medium. Recombinant p97 was purified 40 from spent medium of transfected clone B16SVp97a.14, which shed large quantities of p97 antigen into the medium. Cells were maintained at near confluency (10^9 cells) in 850 cm^2 roller bottles by continually adding small amounts of fresh medium. They continued to shed antigen without detaching for weeks, allowing continual harvest and freezing down of spent medium. The purification of p97 was accomplished by im-
45 munoaffinity chromatography, using sepharose linked to Fab fragments of monoclonal antibody 96.5. To 45 this end, three liters of spent medium was run over a series of three 30 ml columns. The first contained 15 ml of G-25 superfine Sephadex (Pharmacia), the second contained 20 ml of Sepharose 4b (Pharmacia), and the third contained 8 ml of cyanogen bromide-activated Sepharose (Sigma) conjugated to Fab fragments of monoclonal antibody 96.5 (10 mg protein/ml of Sepharose). Subsequently, the affinity column was washed
50 extensively with cold PBS and the antigen was eluted with 30 ml of 0.1 M citrate, pH 5 and 30 ml of 0.1 M 50 citrate, pH 4. These conditions were shown not to alter the immunoreactivity of the antigen, while accomplishing complete elution of the antigen from monoclonal antibody 96.5. The two elutions were neutralized with 3.0 ml and 4.5 ml, respectively, of 2 M Tris, pH 8. The purified eluate was concentrated using an Amicon apparatus with a PM10 filter, and washed with two 10 ml volumes of PBS, leaving a final yield of 4.95
55 mg in 4.5 ml as determined by Bradford assay (Biorad). Fifteen ug of the product was run on SDS-PAGE 55 (Figure 7) and visualized both by Coomassie Blue and silver stain. A double determinant immunoassay (DDIA) (Brown, et al. 1981, Proc. Natl. Acad. Sci. 78:539) provided an independent confirmation of the molar quantity of purified protein. Control preparations were performed in parallel with spent medium from the parental B16 cell line, and showed no detectable protein. In a subsequent preparation 30 mg of 95% pure p97
60 protein was purified from 300 mg of monoclonal antibody 96.5 Fab fragments conjugated to Sepharose. The 60 purified p97 protein was immunogenic producing a strong antibody response in mice immunized with the protein as described in Section 7.3. *infra*.

7.2. *Construction and expression of recombinant p97 vaccinia virus*
65 The coding region of p97 was inserted by cutting p97a with *Hind*III, converting the ends to blunt ends, and 65

given two weeks following the last vaccination by injection of M2SVp97a.2E, a metastatic tumor clone prepared from M2-K1735 (a murine melanoma model) by transfection with the human p97 coding sequence contained in an expression plasmid driven by the SV40 early promoter. A variety of expressing clones were selected, and the one used for tumor challenge, clone M2SVp97a.2E, expresses a medium level of p97, about 400,000 molecules per cell or equivalent to human melanoma p97 antigen density. Two doses of intravenous tumor challenge were used, 5×10^5 or 1×10^5 cells which were injected into the tail vein of syngeneic C3H/Hen mice. The mice were sacrificed 16 days after tumor challenge and lungs were removed. A mouse was scored as positive if there were tumors visible to the naked eye on longs stained with India ink. The results are shown in Table V.

Table V

Challenge of vaccinated mice with syngeneic p97 transfected melanoma cells

Vaccine	No. of Immunizations	Challenge Cell Dose	No. of Mice with Obvious Lung Metastasis
Vp97a-NY	2	5×10^5	1/5
Vp97a-NY	1	5×10^5	2/4
Irradiated Syngeneic Melanoma Cells	2	5×10^5	0/4
Vwt-NY	2	5×10^5	9/10
p97 Protein	2	5×10^5	3/3
Vp97a-NY	2	1×10^5	0/1
Vp97a-NY	1	1×10^5	0/4
Naive	0	1×10^5	5/6

The results presented in Table V demonstrate that there was considerable protective effect with two immunizations of Vp97a.NY although no protective effect was seen with the purified p97 protein vaccine (despite the extremely high antibody titers elicited). The ability of the recombinant virus to elicit cellular immunity may be responsible for its protective tumor immunity.

In a therapy experiment, mice were inoculated with a low dose of p97-expressing tumor cells and then two days later, inoculated with the recombinant vaccinia vaccine. Mice were challenged with 10^5 or 10^4 p97-expressing tumor cells (M2SVp97a.E) intravenously. Two days later, mice were inoculated by tail scarification either with Vp97a-NY or Vwt-NY. Weekly inoculations by tail scarification were repeated, and mouse survival recorded. The results shown in Figure 10 indicate the therapeutic effect of recombinant p97 vaccinia virus vaccination in mice with existing lung metastasis.

7.5.   Recombinant p97 vaccinia virus is immunogenic in macaque monkeys

Two *Macaca fasicularis* (macaque) monkeys were scarified with either 2×10^8 plaque forming units (pfu) of Vp97a-NY recombinant vaccinia, or the same dose of parental strain vaccinia. Two weeks later the sera were tested by ELISA for titers to vaccinia and p97. The results shown in Table VI demonstrate that humoral antibodies to p97 were detectable two weeks after the single inoculation with Vp97a-NY.

Table VI

Serum antibody titers in vaccinia inoculated monkeys

Immunogen/Week	Anti-Vaccinia Titer (serum dilution with twice background)	Anti-p97 Titer (µg/ml monoclonal antibody equivalents)
Vp97a-NY/Week 0	1/20	0.54
Vp97a-NY/Week 2	1/2000	6.54
Vwt-NY/Week 0	1/20	0.50
Vwt-NY/Week 2	1/2000	0.34

8.   Deposit of microorganisms

The following *E. coli* strain carrying the listed plasmid has been deposited with the ATCC, Rockville, MD and has been assigned the following accession number:

carbonate, and 2.5×10^5 M 2-mercaptoethanol. Cultures were pulse-labeled for six hours on day four, with 25 uCi/well tritiated thymidine (New England Nuclear), harvested with a PHD cell harvester, and counted using Optifluor in a Beckman LS 3801 counter. Proliferation indices were calculated by dividing cpm averages of quadruplicate wells stimulated with each antigen by the average cpm average of control (media).

5   The results shown in Table II indicate that T cells are proliferating in response to the p97 protein antigen.

    In order to ascertain whether helper cells were also stimulated by the recombinant virus in spleen cells from immunized mice, the cells were stimulated *in vitro* and the supernatants assayed for production of interleukin-2 (IL-2), a helper T cell factor. Spleen cells were cultured from mice immunized twice previously with recombinant Vp97a-NY vaccinia or parental vaccinia. 10^5 cells were incubated for 48 hours in 0.2 ml of

10 medium identical to that used for proliferation assays, in 96-well round bottom plates, in the presence or absence of the stimulation antigen. Supernatants were collected, pooled from four wells, and frozen prior to IL-2 assay. The IL-2 assay utilized 10^4 previously IL-2 starved mouse T cell line CTLL cells incubated in each well with varying dilutions of assay supernatant with Click's Medium, in triplicate. A standard curve was constructed with recombinant IL-2 obtained from Genentech, CA. CTLL cells were pulse-labeled with thymid-

15 ine according to the usual proliferation assay technique in the last six hours of 24 hour incubation, then harvested and counted as described for the proliferation assay methods. The results shown in Table III indicate that IL-2 production from spleen cells of mice immunized with recombinant p97 vaccinia virus is stimulated *in vitro* by p97.

20 *Table III*

Stimulation of IL-2 production by p97 immune spleen cells

Vaccination Immunogen	In Vitro Stimulus	Units IL-2 Produced
Vp97a-NY	p97 Protein (20 ug/ml)	4.4
Vp97a-NY	Medium	0.25
Vwt-NY	p97 Protein (20 ug/ml)	0.25
Vwt-NY	Medium	0.25

    In addition, a delayed type hypersensitivity response was measured using the foot-pad swelling assay in

35 Vp97a-NY inoculated mice. Five mice (C3H/Hen strain) per group were inoculated by tail scarification with recombinant or parental strain vaccinia virus. Six days later, the hind paws of each mouse were challenged by inoculation of 20 ul PBS or 20 ul cells in PBS (5×10^5 cells per mouse). The foot pads were measured 24 hours later in a double blind manner, using a Fowler micrometer. The foot pad thickness of the PBS-injected foot pad was substracted from the measured thickness of the experimental foot from each mouse, and

40 means as well as standard deviations of the incremental foot pad swelling were calculated. The results shown in Table IV show the induction of p97-specific delayed type hypersensitivity response in mouse immunized with recombinant p97 vaccinia virus.

 Table IV

45

Antigen-specific footpad swelling in p97 immune mice

Vaccination Immunogen	Challenging Antigen	Footpad Swelling $(mm \times 10^{-2})$
Vp97a-NY	p97-transfected syngeneic tumor cells	40.3 (+/− 6.8)
Vp97a-NY	parental syngeneic tumor cells	3.0 (+/− 2.8)
Vwt-NY	p97-transfected syngeneic tumor cells	1.5 (+/− 2.3)
Vwt-NY	parental syngeneic tumor cells	5.5 (+/− 5.0)

60   7.4. *Protection and therapy with p97 vaccinia virus in a murine tumor model*

    In order to assess vaccination efficacy, mice were vaccinated with various protocols using the recombinant p97 vaccinia virus of the invention and then challenged with a p97-transfected syngeneic tumor cell (M2SVp97a.2E). To this end, mice were immunized with Vp97a-NY recombinant live vaccinia virus or the parental strain (Vwt-NY) by tail scarification; or with 100 ug purified p97 protein or 5×10^6 irradiated M2-

65 K1735 tumor cells intraperitoneally in complete Freund's adjuvant. An intravenous tumor cell challenge was

19. The virus according to claim 18 comprising a lambda phage.

20. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or protein of claim 1 or 2 mixed with a pharmaceutical carrier.

21. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or
5 protein of claim 3 mixed with a pharmaceutical carrier.   5

22. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or protein of claim 4 mixed with a pharmaceutical carrier.

23. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or protein of claim 5 mixed with a pharmaceutical carrier.
10   24. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or   10
protein of claim 6 mixed with a pharmaceutical carrier.

25. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or protein of claim 7 mixed with a pharmaceutical carrier.

26. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or
15 protein of claim 8 mixed with a pharmaceutical carrier.   15

27. A subunit vaccine formulation in which the immunogen comprises an effective dose of the peptide or protein of claim 9 mixed with a pharmaceutical carrier.

28. A live virus vaccine formulation comprising the recombinant virus of claim 10 or 11 in which the virus is infectious without causing disease in a host to be vaccinated.
20   29. The live virus vaccine formulation of claim 28 in which the recombinant virus comprises an enveloped   20
virus.

30. The live virus vaccine formulation of claim 29 in which the enveloped virus comprises a vaccinia virus.

31. The live virus vaccine formulation of claim 28 in which the recombinant virus comprises a naked virus.
25   32. The live virus vaccine formulation of claim 31 in which the naked virus comprises an adenovirus.   25

33. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of claim 10 or 11 in a non-infectious state mixed with a pharmaceutical carrier.

34. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of claim 12 in a non-infectious state mixed with a pharmaceutical carrier.
30   35. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of   30
claim 13 in a non-infectious state mixed with a pharmaceutical carrier.

36. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of claim 14 in a non-infectious state mixed with a pharmaceutical carrier.

37. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of
35 claim 15 in a non-infectious state mixed with a pharmaceutical carrier.   35

38. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of claim 16 in a non-infectious state mixed with a pharmaceutical carrier.

39. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of claim 17 in a non-infectious state mixed with a pharmaceutical carrier.
40   40. An inactivated virus vaccine formulation comprising an effective dose of the recombinant virus of   40
claim 18 or 19 in a non-infectious state mixed with a pharmaceutical carrier.

41. A recombinant DNA vector comprising p97b.

42. A unicellular organism containing the recombinant DNA vector of claim 41.

43. A bacterium containing the recombinant DNA vector of claim 41.
45   44. A bacterium of claim 43 comprising *Escherichia coli* as deposited with the ATCC and assigned acces-   45
sion number 53403, or a mutant, recombinant or genetically engineered derivative thereof.

45. A recombinant DNA vector comprising pMTp97b.

46. A cell line containing the recombinant DNA vector of claim 45.

47. The cell line of claim 45 comprising TKMp97-12 as deposited with the ATCC and assigned accession
50 number CRL 8985 or a mutant, recombinant or genetically engineered derivative thereof.   50

48. A recombinant DNA vector comprising pSVp97a.

49. A cell line containing the recombinant DNA vector of claim 48.

50. The cell line of claim 49 comprising B16SVp97a.14 as deposited with the ATCC and assigned acces- sion number CRL 9304 or a mutant, recombinant or genetically engineered derivative thereof.
55   51. The virus according to claim 13 comprising virus Vp97a-NY as deposited with the ATCC and assigned   55
accession number VR 2159, or a mutant, recombinant or genetically engineered derivative thereof.

E. coli Strains	Plasmid	Accession Number[a]
E. coli HB101	p97b	53,403

5

The following recombinant vaccinia virus has been deposited with the ATCC, Rockville, MD, and has been assigned the following accession number:

10	Virus	Accession Number[b]		10
	Vp97a-NY	VR 2159		

The following cell lines carrying the listed plasmids have been deposited with the ATCC, Rockville, MD, and have been assigned the following accession numbers:

15   15

Cell Line	Plasmid	Accession Number
TKMp97-12	PMTp97b	CRL 8985[c]
(Mouse cell)		
B16SVp97a.14	pSVp97a	CRL 9304[d]
20 (mouse melanoma			20
cell)		

The present invention is not to be limited in scope by the microorganisms and cells deposited since the deposited embodiment is intended as single illustration of one aspect of the invention and any mic-
25 roorganisms or cells which are functionally equivalent are within the scope of this invention. Indeed, various   25
modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

It is also to be understood that all base pair sizes given for nucleotides are approximate and are used for
30 purpose of description.   30
    a Deposit date: 27 December 1985
    b Deposit date: 6 January 1987.
    c Deposit date: 27 December 1985
    d Deposit date: 6 January 1987.

35   35
CLAIMS

    1. A substantially pure antigenic peptide or protein related to the melanoma-associated p97 antigen.
    2. The peptide or protein according to claim 1 having an amino acid sequence comprising the amino acid
40 sequence substantially as depicted in Figure 3 or any antigenic portion thereof.   40
    3. The peptide or protein of claim 1 or 2 which the peptide or protein was purified from a cultured cell containing a nucleotide sequence encoding the peptide or protein which is under the control of a second nucleotide sequence that regulates gene expression so that the peptide or protein is expressed by the cultured cell.
45   4. The peptide or protein of claim 3 in which the cultured cell comprises a microorganism.   45
    5. The peptide or protein of claim 4 in which the microorganism comprises a bacteria.
    6. The peptide or protein of claim 4 in which the microorganism comprises yeast.
    7. The peptide or protein of claim 3 in which the cultured cell comprises an animal cell line.
    8. The peptide or protein of claim 3 in which the cultured cell comprises an insect cell line.
50   9. The peptide or protein of claim 1 or 2 in which the peptide or protein was chemically synthesized.   50
    10. A recombinant virus, the genome of which comprises a nucleotide sequence encoding an antigenic peptide or protein related to the melanoma-associated p97 antigen, or an antigenic portion thereof which is under the control of a second nucleotide sequence that regulates gene expression so that a peptide or protein related to the melanoma associated p97 antigen is expressed in a host infected with the virus.
55   11. The recombinant virus according to claim 10 in which the nucleotide sequence encoding an antigenic   55
peptide or protein related to the melanoma-associated p97 antigen comprises the nucleotide sequence substantially as depicted in Figure 3 or any portion thereof encoding an antigenic peptide or protein.
    12. The virus according to claim 10 or 11 comprising an enveloped virus.
    13. The virus according to claim 12 comprising a vaccinia virus.
60   14. The virus according to claim 10 or 11 comprising a naked virus.   60
    15. The virus according to claim 14 comprising an adenovirus.
    16. The virus according to claim 10 or 11 comprising a nuclear polyhedrosis virus.
    17. The virus according to claim 16 comprising a baculovirus.
    18. The virus according to claim 10 or 11 comprising a bacteriphoage.